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# MAHA BHASKARIYA

## (ASTRONOMY & MATHEMATICS)

MAHA BHASKARIYA (ASTRONOMY & MATHEMATICS)

By BHASKARACHARYA – I (628 AD)

[English Translation Only]

Prepared Based on the Translation by

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**Chapter - I**

**MEAN LONGITUDE OF A PLANET**

**AND PLANETARY PULVERISER**

1. I bow to God Sambhu who bears on His forehead a digit of the Moon illumining all directions by its rays, to Him whose feet are adored by the gods and who is the source of all knowledge.

2. Glorious are the rays of the Sun which make the lotus blossom forth, (and those) of the Moon whose beauty is like that of the damsel's face, (as also are) the long and clear rays of the stars including Jupiter; so also the lustre of Mars, Mercury, Saturn and Venus.

3. May the accurate *Asmaka-tantra (asmakam sphutatantram)*, which has been acquired by penance, live long in the world for its excellent qualities. May also the pupils of (Arya) bhata, who are free from sins and have conquered the enemies of passions, live long.

**MEAN LONGITUDE OF A PLANET**

A rule for calculating the *ahargana* :

4-6. Add 3179 to the number of elapsed years of Saka kings; then multiply (that sum) by 12; and then add the number of months elapsed (since the beginning of Caitra). Put down the result at two places. At one place multiply

(that) by the number of intercalary months in a yuga and divide by the number of solar months in *yuga*; and divide by the number of solar months in a *yuga*; and add the resulting intercalary months (omitting the fractionof a month) to the result put at the other place. Multiply the tsum by 30 and then add the number of lunar days (*tithis*) elapsed (since the beginning of the current month). Set down the result (i.e., the sum obtained) at two places. At one place multiply that by the number of lunar days (in a *yuga*), and subtract the resulting omitted lunar days (neglecting the fraction of a day) from the result set down at the other place. The result (thus obtained) is the number of (mean) civil days elapsed since the beginning of Kaliyuga (at mean sunrise at Lanka on the given lunar day). These days are said to have commenced with Friday and at sunrise (at Lanka).

7. Or, multiply the number of (solar) months elapsed (since the beginning of Kaliyuga) by the number of lunar months (in a yuga) and divide by the number of solar months (in *yuga*). Reduce the quotient to days (and add the number of lunar days elapsed since the beginning of the current lunar month); then multiply by the number of civil days (in a *yuga*) and divide by the number of lunar days (in a *yuga*); the quotient denotes the *ahargana*.

8. If from the civil days (corresponding to a *yuga*) we get the tabulated revolutions of a planet, how many of those (revolutions) will we get from the civil days elapsed since the begining of Kaliyuga? Thus (i.e., by applying this proportion) are obtained the revolutions (performed by the planet), and then successively the signs, degrees, minutes, seconds, and thirds (of the planet's means longitude). (A rule for derving the mean longitude of a planet from that of the Sun)

9. Reduce the Sun's mean longitude (given in terms of signs, degrees, and minutes) together with the years elapsed (treated as revolutions) to minutes of arc. Multiply them by the planet's own revolution number stated in the *Gitika* and divide (the product) by the number of (solar) years in a yuga. The result, say (the learned), is the planet's mean longitude in terms of minutes.

A rule for deriving the mean longitude of a planet from the mean longitude of a Moon or a planet or the ucca of planet.

10. The (mean) longitude of the Moon, the planet, or the ucca (whichever is known) together with the revolutions performed should be reduced to minutes. The resulting minutes should then be multiplied by the revolution-number of the desired planet and (the product obtained should be) divided by the revolution-number of that (known) planet. The result is (the mean longitude of the desired planet) in terms of minutes.

11. Or, multiply the ahargana by the number of intercalary months in a *yuga* and divide (the product) by the number of civil days (in a *yuga*): the result is in terms of revolutions, etc. Add that to thirteen times the mean longitude of the Sun. (This is the process) to obtain the mean longitude of the Moon.

12. Or, substract the result obtained (in revolutions etc.) from the mean longitude of the Moon and take one-thirteenth of the remainder: this is stated to be the mean longitude of the Sun by the mathematicians whose intellect has been awakened by the grace of the teacher.

A rule for calculating the mean longitudes of the Sun and the Moon without making use of the *ahargana*:

13-19. For one (desirous of) calculating the mean longitudes of the Moon and the Sun without the use of the ahargana, the following method is stated :

Reduce the years (elapsed since the beginning of Kaliyuga) to months, and add to them the elapsed months (of the current year). Then multiply that (sum) by 30, and add the product to the number of (lunar) days elapsed since the beginning of the current month. Multiply that (sum) by the number of intercalary months (in a yuga) and divide by the number of solar months in a *yuga* reduced to days: the quotient denotes the number of intercalary months (elapsed). Delete (or rub out) the divisor and divide the remainder (called *adhimasesa*, i.e., the residue of the intercalary months) by the number of lunar months (in a *yuga*): Thus are obtained degrees, minutes, seconds, and thirds. Then multiply the (concept) intercalary months elapsed by 30 and to the product add the number of solar days (elapsed since the beginning of Kaliyuga); then multiply that (sum) by the number of omitted lunar days in a *yuga* and divide by the number of lunar days (in a *yuga*): the remainder obtained is (the *avamasesa*, i.e, the residue of the omitted lunar days) called ahnika. Then multiply the *avamasesa* by the number of intercalary months (in a *yuga*) and divide by the number of civil days (in a yuga). Add the resulting quotient to the *adhimasasesa* and then apply the process stated above (i.e, divide by the number of lunar months in a *yuga*: the result is in degrees, minutes, etc. This is the total *adhimasasesa*). Next multiply the avamasesa called *ahnika* by 60 and divide by the number of civil days in a *yuga*: the result is in minutes, seconds, and thirds respectively. The number of months elapsed (since the beginning of Caitra) are to be taken as signs, and the number of lunar days elapsed (of the current month) as degrees. (The sum of these signs and degrees and the minutes, seconds, etc. corresponding to the *avamasesa* in the *grahaanu*). From thirteen times and from one time that (*grahatanu*) severally substract the degrees, minutes, etc. corresponding to the (total)

*adhimasasesa*: the remainders (thus obtained) are stated by the wise astronomers to be the mean longitudes of the Moon and Sun (respectively) conforming to the teaching of (Arya)bhata.

The process described in the above rule is not in proper sequence. The direction given in verse 15 ought to have been after verse 17. Stated in proper sequence, the rule would be :

"Reduce the years (elapsed since the beginning of Kaliyuga) to months, and add to them the elapsed months (of the current year). Then multiply the sum by 30, and add the product to the number of (lunar) days elapsed since the beginning of the current month. Multiply that sum by the number of intercalary months (in a yuga) and divide by the number of solar months in a yuga reduced to days: the quotient denotes the number of intercalary months (elapsed). (The remainder is the adhimasasesa). Multiply the (complete) intercalary months (thus obtained) by 30 and to the product add the number of solar days (elapsed since the beginning of Kaliyuga)[1]; then multiply that (sum) by the number of omitted lunar days in a *yuga* and divide by the number of lunar days (in a yuga); the remainder obtained is (the avamasesa) called ahnika. Then multiply the *avamasesa* (called *ahnika*) by the number of intercalary months (in a yuga) and divide by the number of civil days in a *yuga*: the result is in minutes, seconds, and thirds, etc. The number of months elapsed (since the beginning of Caitra) are to be taken as signs and the number of lunar days elapsed (of the current month) as degrees. (The sum of these signs and degrees, and the minutes, seconds, etc. corresponding to the *avamasesa* is the *grahatanu*). From thirteen times and from one time that (*grahatanu*) severally, subtract the degrees, minutes, etc. corresponding to the (total) *adhimasesa*: the remainders (thus obtained) are stated by the wise astronomers to be the mean longitudes of the Moon and the Sun (respectively) conforming to the teachings of (*Arya*)bhata."

Another rule for finding the mean longitude of a planet :

20. Divide the (*yojanas* of the) circumference of the sky by the numbers of civil days (in a *yuga*) : the result is the number of *yojanas* traversed (by a planet per day. By those (*yojanas*) multiply the *ahargana* and then divide (the product) by the length (in *yojanas*) of the own orbit of the planet. From that are obtained the revolutions, signs, etc. (of the mean longitude of the planet).

Introduction to the topic discussed in the succeeding eighteen stanzas:

21. After a careful study of the ocean of the Asmakiya sastras (sastrarnavam asmakiyam) I reveal the planetary procedure, the secret there, (hitherto) unnoticed by the other followers of the Asmakiya (asmakiyih) by means of simplified rules (laghu-tantra)

22. Always having ascertained the number of years (elapsed since the beginning of Kaliyuga), multiply them by 11 and by 389/6000 (separately). Add the two results and divide the sum (thus obtained) by 30. The quotient of division denotes (the mean intercalary) months, and the remainder (the means intercalary) days.

23. Multiply (the number of years elapsed since the beginning of Kaliyuga) by 29 as divided by 36 (i.e., by 29/36). Again multiply the same (number of years) by 43 and divide by 72000. The sum of the two quotients gives the (residual mean omitted lunar) days. (Multiply the remainder of the first division by 2000, increase the product by the remainder of the second division, and then) divide (the sum) by 1125: then are obtained (the mean lunar) days (which have elapsed at the beginning of the mean solar year since the occurrence of mean omitted lunar day).

24. From them (i.e. from the mean lunar days elapsed at the beginning of the mean solar year since the occurrence of a mean omitted lunar day) subtract the mean intercalary days (obtained in stanza 22 above): the remainder (obtained) is the time (in terms of mean lunar days) elapsed (at the commencement of mean Caitra) since the fall of a (mean) omitted lunar day. In case the subtraction is not possible, add 64 (to the minuend) and then from the sum perform the subtraction.

The subtraction is not possible when a mean omitted lunar day happens to fall between the beginning of mean Caitra and the beginning of the mean solar year. In such a case the omitted lunar days (obtained in stanza 23) should be diminished by one.)

A rule for finding the lord of the year:

25-26 (i). Divide the sum of the months (which have elapsed at the beginning of the mean solar year since the beginning of Kaliyuga) and the (corresponding complete mean) intercalary months (obtained in stanza 22) by seven; and multiply the remainder by 30. Now we say what is to be subtracted from this: Divide the number of years elapsed since the beginning of Kaliyuga by seven and multiply the remainder (of the division) by five, add this product to the number of (residual mean) omitted lunar days (obtained in stanza 23) and divide the sum by seven: the remained (of this division is the quantity to be subtracted). (Divide the difference of this quantity and the one obtained previously, by seven). The remainder increased by one counted with Friday gives the lord of the year (i.e. the planet presiding over the first day of Caitra). So has been stated by the learned.

A rule for finding the number of mean omitted lunar days occurring since the fall of the mean omitted lunar day just before the beginning of mean caitra:

26.(ii) Increase the number of (lunar) days (elapsed since the beginning of Caitra) by the number of (mean lunar) days elapsed (at the beginning of Caitra) since the fall of a mean omitted lunar day, and divide that (sum) by 64: the quotient gives the number of (mean) omitted lunar days (which have occurred since the mean omitted lunar day occurring before the beginning of Caitra):

27-28. Multiply the number of years (elapsed since the beginning of Kaliyuga) by 149 and then divide by 576: the quotient is in terms of days. Add these days to ten times the number of years (elapsed): thus are obtained the so called ravija days. To the ravija days add the (residual mean) omitted lunar days obtained above (in stanza 23). From the sum subtract the (complete mean) intercalary months (obtained in stanza 22) as multiplied by 30. Whatever is obtained as the remainder is "the subtractive for the (current) year. When the subtraited is greater, then the difference in prescribed as "the additive".

29. The number of years elapsed (since the commencement of Kaliyuga) multiplied by 360 is always called *grahatanu*. The (mean) longitudes (reduced to degrees) of the planets (Sun, Mercury, and Venus) together with the *grahatanu* are called *dhruvaka* by the learned.

The term *grahatanu* denotes the number of mean solar days elapsed at the beginning of the mean solar year since the beginning of Kaliyuga. This *grahatanu*, as remarks the commentator Paramesvara, is really a part of the grahatanu.

The *dhruvaka* (i.e. complete *grahatanu*) denotes the number of mean solar days elapsed on the given lunar day since the beginning of Kaliyuga. The above *dhruvaka*, or *grahatanu*, is defined for the Moon, Mars, Jupiter, and Saturn only; that for the Sun, Mercury, and Venus is defined in the next stanza.

The *grahatanu* for the Sun, Mercury, and Venus :

30. Diminish the (lunar) days elapsed since the beginning of Caitra by the corresponding complete omitted lunar days obtained in the second half of stanza 26) and divide (the difference) by seven : the remainder (of the division) day. From that, the "subtractive" for the year (obtained in stanzas 27-28) should also be subtracted. (But it must be remembered that the minuend of this substraction is the difference of the previous substraction and not the other (i.e. not the remainder of the division). The remainder obtained by subtracting the "*subtractive*" is the grahatanu for the Sun, Mercury, and Venus. It denotes the number of mean civil days elapsed since the beginning of the mean solar year).

The number of mean civil days elapsed since the beginning of the mean solar year is generally known as *laghvahargana* ("smaller ahargana")

A rule for finding of the mean longitudes of the Sun, Mercury, and Venus:)

31. Divide the *grahadeha* (for the Sun) by 70: the result is in days, etc. Then multiply one-fifth of the *grahadeha* by 2: the result is in vighatikas. These (days and *vighatikas*) subtracted from the *grahadeha* are stated to be (the degrees, minutes, etc. of) the mean longitudes of the Sun, Mercury and Venus.

A rule for finding the mean longitude of the Moon:

32. Multiply the grahatanu for the Moon by 83 (lit. $9^2 + 2$) and divide by 225; the result is in terms of degrees, etc. From that substract the seconds obtained by multiplying the grahatanu by 11 and dividing by 50. (Then add the remainder to thirteen times the mean longitude of the Sun as prescribed in stanza 35 below : the sum thus obtained is the mean longitude of the Moon).

A rule for finding the mean longitude of the Moon's ascending node:

33. Divide (the *grahatanu*) by 270: these are degrees. Multiply (the *grahatanu*) by 113 and divide by 600: these are seconds. These together with one-twentieth part of the (mean) longitude of the Sun (in revolution, etc. ) constitute the (mean) longitude of the Moon's ascending node.

A rule for finding the mean longitude of the Moon's apogee:

34. Multiply the *grahatanu* by seven and divide by nine : these are minutes. Then multiply the *grahatanu* by 11 and divide by 60: these are seconds. Then divide the *grahatanu* by 20: these are thirds to be subtracted. These together with one-tenth of the Sun's (mean) longitude (in revolutions, etc.) constitute the (mean) longitude of the Moon's apogee:

A rule for finding the mean longitude of the *sighrocca* of Venus, and also giving the additives for the *sighrocca* of Mercury and the Moon:

35. Multiply the grahatanu by 37 and divide by 900 : these are the degrees, etc., (forming part) of the (mean) longitude of (the sighrocca of) Venus. Then divide the grahatanu by 100: these are seconds. Add to these one-third of the Sun's (mean) longitude (in revolutions, etc.). Then subtract the whole of that (sum) from two times the Sun's (mean) longitude. (The difference thus obtained is the mean longitude of the sighrocca of Venus).

A rule for finding the mean longitude of the sighrocca of Mercury :

36. Divide the *grahatanu* by 200: the result is in terms of signs. Then divide the grahatanu by 8: these are minutes. Then divide the *grahatanu* by 8: these are minutes. Then divide the *grahatanu* by 6); these are seconds. Adding all these (and also four times the Sun's mean longitude as prescribed in stanza 35) is obtained the (mean) longitude of (the *sighrocca* of )Mercury.

A rule for finding the mean longitude of Saturn:

37. Multiplying the grahatanu by 8 and dividing by 225 are obtained minutes; and dividing (the grahatanu) by 300 are obtained seconds. Adding these two together and increasing that (sum) by one-thirtieth of the Sun's (mean) longitude is obtained the (mean) longitude of Saturn.

A rule for finding the mean longitude of Mars:

38. Multiply the *grahatanu* by two and subtract one-twentieth of itself from that: these are minutes, etc. Then divide the *grahatanu* by 50: these are seconds. Add these (minutes and seconds) to half the Sun's (mean) longitude (in revolutions, etc.) the sum is the (mean) longitude of Mars.

A rule for finding the mean longitude of Jupiter:

39. Multiply the grahadeha by 22 and divide by 375 : these are minutes, etc. Add them to one-twelfth of the Sun's (mean) longitude (in revolutions, etc.): the result is the (mean) longitude of Jupiter.

Corrections to be applied to the mean longitudes of the Moon's apogee and ascending node, and to the *ahargana*:

40. Add three signs to the mean longitude of the Moon's apogee. Subtract the (mean) longitude of the Moon's ascending node from 12 signs and then add 6 signs. Also (if necessary) add *one* to the *ahargana* obtained by proportion (in stanza 7 above). So say the astronomers whose hearts are devoted to Aryabhata's system of astronomy (*bhatasastra*)

**PLANETARY PULVERISER**

Preliminary operation to be performed on the divisor and divided of a pulveriser:

41. The divisor (which is "the number of civil days in a *yuga*) and the divident (which is "the revolution-number of the desired planet") become prime to each other on being divided by the (last non-zero) residue of the mutual division of the number of civil days in a yuga and the revolution -number of the desired planet. The operations of the pulverisor should be performed on them (i.e. on the abraded division and abraded dividend). So has been said.

A rule for solving a pulveriser, when the dividend is smaller than the divisor:

42-44. Set down the dividend above and the divisor below that. Divide them mutually, and write down the quotients of division one below the other (in the form of a chain). (When an even number of quotients are obtained) think out by what number the (last) remainder be multiplied so that the product

being diminished by the (given) residue be exactly divisible (by the divisor corresponding to that remainder). Put down the chosen number (called *mati*) below the chair and then the new quotient underneath it. Then by the chosen number multiply the number which stands just above it, and to the product add the quotient (written below the chosen number). (Replace the upper number by the resulting sum and cancel the number below). Proceed afterwards also in the same way (until only two numbers remain). Divide the upper number (called "the multiplier") by the divisor by the usual process and the lower one (called "the quotient") by the dividend: the remainder (thus obtained) will respectively be the *ahargana* and the revolutions, etc. or what one wants to know.

An alternative rule :

45-46(i) Alternatively, the pulveriser is solved by subtracting *one* (i.e., by assuming the residue to be unity). The upper and lower quantities (in the reduced chair) are the (corresponding) multiplier and quotient (respectively). By the multiplier and quotient (thus obtained) multiply the given residue, and then divide the respective products by the abraded divisor and dividend. The remainders obtained are here (in astronomy) the *ahargana* and the revolutions (performed respectively).

(A rule for finding the residue of revolutions from the longitude of a planet given in signs, etc.:)

46. (ii) (In case the longitude of a planet is given in terms of signs, etc.,) the signs, etc., are multiplied by the abraded number of civil days (in a yuga) and the product is divided by the number of signs, etc., (in a circle). The quotient is stated to be the residue (of revolutions).

A rule for solving a pulverser when the dividend is greater then the divisor:

47. When the dividend is greater than the divisor, then, having subtracted the greatest multiple of the divisor (from the dividend), apply the same process (as prescribed in stanzas 42-44 or 45-46 (i)). Multiply the multiplier (thus obtained) by that multiple and (to the product and the quotient: the result will be the quotient here (required).

A rule for solving the so called vara-kuttakara (week-day pulveriser)

48. Divide the abraded number of civil days (in a *yuga*) by 7. Take the remainder as the dividend, and 7 as the divisor. Also take the excess 1m 2m etc,m of the required day over the given day as the residue. Whatever number (i.e. multiplier) results on solving this pulveriser is the multiplier of the abraded number of civil days. The product of these added to the ahargana calculated (for the given day) gives the ahargana for the required day.

A rule for the solution of the so called vela-kuttakara (time-pulveriser):

49. First make the abraded dividend and the (new) divisor prime to each other. Then by what remain as the (new) divisor multiply the abraded divisor (and also the residue), Thereafter the process for the time-pulveriser is the same as described before (for the ordinary pulveriser)

This rule is applicable when the ahargana is not a hole number but a whole number and a fraction.

50. (To obtain the other solutions of the pulveriser) the intelligent (astronomer) should again and again add the divisor to the multiplier and the dividend to the quotient as in the process of *prastara* ("representation of combinations")

51. When the part (of the revolution) to be traversed by some (planet) is the given quantity, then (also) the same process should be applied, treating the part to be traversed as the additive, or taking unity as the additive. All details of procedure are the same (as before).

Rules relating to the two cases: (i) when the sum or difference of the residues (of revolutions) of any two planets is given, and (ii) when the residues for two or more planets are given separately:

52. When the sum of the residues (of revolutions of two or more planets) is given, proceed with the sum of their revolution-numbers (as the dividend); and when the difference between the residues (for any two planets) is given, proceed with the difference of their revolution-numbers (as the dividend). When the residues (for two or more planets) are given (separately), think out the methods of solution by the help of the given residues and the true revolution-numbers of the given planets.

**Chapter - II**

**THE LONGITUDE-CORRECTION**

Names of certain places lying on the Hindu Prime meridian:

1-2. From Lanka (towards the north, we have the following places on the prime meridian): Kharanagara, Sitorugeha, Panata, Misitapuri, Taparni, the lofty mountain called Sitavara, the wealthy town called Vatsyagulma, the well known Vananagari, Avanti, Sthanesa, and then Meru, which is inhabited by happy people. For those who reside in these places, the correction for the longitude (of the local place) does not exist.

Lanka in Hindu astronomy denotes the place where the Hindu prime meridian passing through Ujjain intersects the equator (i.e. , the place in 0 latitude and 0 longitude). It is one of the four hypothetical cites on the equator, called Lanka, Romaka, Siddhapura, and Yamakoti. Lanka is described in the Surya-siddhanta as a great city (mahapuri) situated on an island (dvipa) to the south of Bharata-varsa (India). The island of Ceylon which bears then name

Lanka, however, is not the astronomical Lanka, as the former is about six degrees to the north of the equator.

Kharanagara ("the town of Khara") is probably the place near Nasik where Khara, cousin of Ravana, lived. Sitorugeha has not been identified.

Panata seems to have been an important place, as it has been mentioned by other astronomers also, such as Lalla, Vatesvara, and Sripati. We have not been able to identify this place also.

Misitapuri and Taparni, too remain unidentified. Sankaranarayana in his commentary on the Laghu-Bhaskariya pronounces misitapura as Nisitapura, so it is difficult to say which prounciation is correct.

The Sitavara mountain ("the excellent white mountain") in the Svetasaila of Lalla, the Sitadri of Sripati, and the Sitaparavata of Bhaskara II. According to Sripati, it is the seat of the six faced god Svamikartikeya. It can therefore be identified with Kraunca-girl or Kumara-parvata, situated at a distance of 3 yojanas from Srisaila.

Vatsyagulma is the town of Vatsaraja Udayana, usually called Vatsapattana. It has been identified with Kausambi (modern Kosam) situated on the river jumna at a distance of about 38 miles from Allahabad.

Vananagari is probably Tumba-vana-nagara (modern Tumain) in Madhya Bharata. Avanti is modern Ujjain. Sthanesa is sthanesvara, a place in Kuruksetra. Meru is north pole.

From the above identification we find that the places mentioned in the text do not lie precisely on one meridian. The places mentioned by other astronomers also do not satisfy this requirement. It has not been possible to give any satisfactory explanation to this discrepancy. Probably the geographical knowledge of ancient Hindu writers was not sound in respect of places other then their own.

A rule for finding the distance of a place from the primemeridian :

3-4 Subtract the degrees of the latitude of one of the places (lit. towns) mentioned above from the degrees of the (local) latitude; then multiply (the degreesof the difference) by 3299 minus 8/25, and divide (the product) by the number of degrees in a circle (i.e., by 360). The resulting *yojanas* constitute the upright (*koti*). The oblique distance between the local place (on the prime meridian) chosen above, which is known in the world by the utterance of the common people, is the hypotenuse. The square root of the difference between their squares (i.e., between the squares of the hypotenuse and the upright) is defined by some astronomers to be the distance (in yojanas of the local place from the prime meridian).

Criticism of the above rule :

5. The distance (obtained above) has been stated to be incorrect by the disciples of (Arya)bhata, who are well versed in astronomy, on the ground that

the method of knowing the hypotenuse is gross. (Those) wise people further say that on account of the sphericity of the earth (also), the method used for deriving the above rule commencing with "aksa" is inaccurate.

Criticism of anothe rule :

6. Some (astronomers) say that the minutes of the difference between the true longitude of the sun calculated from the midday shadow (of the gnomon at the local place) and the true longitude of the sun calculated (from the ahargana) for the middle of the day (without the application of the longitude-correction) give the longitude (correction for the Sun). this also is not so, because for people who live on the same parallel of latitude, the latiaude (and therefore the shadow of the gnomon) is the same.

A rule for finding the longitude in time :

7. Those who have studied the astronomical *tantra* composed by (Arya)bhata and are well versed in Spherics state that the difference between the time of an eclipse calculated by the usal method from the longitudes of the Sun and the Moon (both) uncorrected for the longitude-correction and the time of the eclipse determined by observation is the more accurate value of the (longitude in) time.

Another rule ;

8. On any day calculate the longitude of the sun and the moon for sunrise or sunset without applying the longitude-correction, and therefrom find the time (since sunrise or sunset), in *ghate*s, of rising or setting of the Moon; and having done this, note the corresponding time in *ghatis* from the water-clock. The difference (between the two times), say the astronomers well versed in the *tantra* (composed by Aryabhata), is (the time of rising at the local place of a portion of the ecliptic equal to the motion-difference of the Sun and Moon corresponding to) the local longitude in time. (From this, the local longitude in time may be easily derived).

Criteria for knowing whether the local place is to the east or to the west of the primemeridian :

9. When the rising of a planet is observed before the computed time or the first contact of an eclipse is observed after the computed time, the observer is to the east of the prime meridian. In the contrary case, he is to the west (of the prime meridian).

The longitude correction and its application :

10(i). Multiply the (mean) daily motion of a planet, the sun, or the Moon's ascending node by the longitude in *ghatis* and divide by 60. Apply the resulting correction to the (corresponding) mean longitude of the planet, the Sun, or the Moon's ascending node (calculated for mean sunrise at Lanka) positively or negatively according as the local place is to the west or east of the prime meridian. (Thus is obtained the mean longitude of the planet, the Sun, or the Moon's ascending node for mean sunrise at the svaniraksa place)

Rule for finding the length of the local circle of latitude and the distance of the local place from the prime meridian :

10(ii). Multiply the number of (*yojanas in*) the Earth's circumference by the Rsine of the colatitude and divide by the radius; (the result is the number of *yojanas* in the local circle of latitude). Multiply that by the longitude in *ghatis* and divide by 60; the result (thus obtained) is stated to be the (distance in) *yojanas* (of the local place from the prime meridian).

## CHAPTER III

## DIRECTION, PLACE AND TIME. JUNCTION-STARS OF THE ZODIACAL ASTERISMS AND CONJUNCTION OF PLANETS WITH THEM

### (1) DIRECTION, PLACE AND TIME.

Setting up of the gnomon :

After having tested the level of the ground by means of water, draw a neat circle with a pair of compasses. (At the centre of that circle, set up a vertical gnomon). The gnomon should be large, cylindrical, massive, and tested for its perpendicularity by means of four threads with plumbs tied to them.

A rule for finding the directions :

2. With the two points where the shadow (of the gnomon) enters into and passes out of the circle, neatly draw a fish-figure (lit. fish). The thread-line which goes through the mouth and tail of the fish-figure indicates the north and south directions with respect to the gnomon.

An alternate rule :

3. With the three points (at ends of the three shadows of the gnomon) corresponding to (any three) different times (in the day), draw two fish-figures (each with two of the three points) in accordance with the usual method . From the point of intersection of the lines passing through the mouth and tail (of the two fish-figures), determine the north and south directions.

According to this rule, the north-south line is the one joining the foot of the gnomon with the point of intersection of the mouth-tail lines of the two fish-figures.

A rule for getting the length of the hypotenuse of the shadow :

4. The square root of the sum of the squares of the gnomon and its shadow( is equal to the hypotenuse of the shadow : thus), say the learned (astronomers), is always the semi-diameter of its own circle in the calculations with the shadow.

Rules for finding the latitude and colatitude and the zenith distance and latitude of th sun:

5. Multiply the radius by (the length of) the shadow and (at another place) by (the length of) the gnomon. Divide (the two results) seperately by the square root (obtained above). When this calculation is performed for an equinoctial midday, the (two) results denote the Rsine of the latitude and the Rsine of the colatitude (respectively); elsewhere, they denote the great shadow (i.e., the Resine of the Sun's zenith distance) and the great gnomon (i.e., The Rsine of the Sun's altitude) (respectively).[1]

Rules for determining the declination , day-radius, earthsine, and ascensional difference (for the Sun or a point on the ecliptic)

6-7 Multiply the Rsine of the given longitude by 1397 and always divide by the radius; the result is the Rsine of the declination for that time. Substract the square of that (Rsine of the declination) from the square of the radius and then take the square root (of the difference); the result is called the day-radius. Multiply the Rsine of the latitude by (the Rsine of) the colatitude: the result is the earthsine. Multiply the earthsine by the radius and then divide (the product) by the day-radius; then reduce (the resulting Rsine) to arc. Whatever (arc) is thus obtained is termed " the ascensional difference" by the best amongst the good (astronomers).

A rule for finding the ascensional differences of the (*sayana*) signs Aries, Taurus, and Gemini :

8. Twenty-four multiplied by ten (i.e., 240), 192, and 81- these when (successively) multiplied by the *angulas* of the equinoctial midday shadow and (the products thus obtained) divided by four become the *asus* of the ascensional differences corresponding to Aries, Taurus, and Gemini espectively.

The numbers 240, 192, and 81 given above are four times the ascensional differences in *asus* of the signs, Aries, Taurus, and Gemini respectively for a place having one *angula* for the equinoctial midday shadow.

A rule for finding the times of rising of the (*sayana*) signs at the equator :

9. (Severally) multiply the Rsines of (one, two, and three) signs by 3141 and divide (each of the products) by the corresponding arcs, and then diminish each arc by the preceding arc (if any). The residues obtained after subtraction are the times (in asus) of rising of the signs Aries, Taurus, and Gemini at the equater.

Times of rising of the (*sayana*) signs, Aries, Taurus, and Gemini at the equater and a rule for finding the times of rising of the (*sayana*) signs at the local place :

10. Those who know astronomical methods have found them (i.e., the times of rising of Aries, Taurus, and Gemini at the equater) to be 1670, 1935 (*asus* respectively). These respectively diminshed and the same reversed and increased by the corresponding ascensional differences are the times (in asus)

of rising of the six signs begining with Aries at the local place. (The same in the inverse order are the times of rising of the six signs beginning with Libra at the local place.)

A rule for the determination of the merdian zentih distance and meridian altitude of the Sun with the help of the Sun's declination and the latitude of the place :

11. The difference or the sum of the Sun's declination and the latitude (of the place) according as the Sun is in the six signs beginning with Aries or in the six signs bginning with Libra is the Sun's meridian zenith distance of the midday Sun).

90 degrees (literally, a quadrant of a circle) minus the degrees of the (Sun's) meridian zenith distance is the (Sun's) meridian altitude.

The Rsine of the degrees of the Sun's meridian zenith distance is the great shadow; and the other (i.e.,the Rsine of the Sun's meridian altitude) is the great gnomon.

An alternate rule for finding the Sun's meridian altitude :

12. Or, take the sum or difference of the earthsine and the day-radius according as the Sun is in the northern or southern hemisphere; then multiply that (sum or difference) by (the Rsine of ) the colatitude and divide by the radius. The result thus obtained is the Rsine of the Sun's altitude at midday.

A rule for determining the Sun's declination with the help of the sun's meridian zenith distance and the latitude of the local place, when the latitude is greater than the Sun's meridian zenith distance :

13. When the latitude is greater than the arc of the Sun's meridian zenith distance derived from the (midday) shadow (of the gnomon), their difference is the declination of the apparent Sun. The Sun is also, in that case, in the northern hemisphere.

A rule for determining the Sun's declination with the help of the Sun's meridian zenith distance and the latitude of the local place, when the midday shadow of the gnomon falls to the south of the gnomon :

14. When the (midday) shadow (of the gnomon) falls to the south (of the gnomon) then the sum of the latitude and the Sun's true meridian zenith distance gives the declination of the Sun lying in the northern hemisphere.

A rule for finding the sun's declination with the help of the latitude and the Sun's meridian zenith distance, when the Sun's meridian zenith distance is

greater than the latitude and the shadow of the gnomon falls towards the north of the gnomon :

15. When the Sun's meridian zenith distance is greater than the latitude then the latitude is always substracted from that (i.e., from the Sun's meridian zenith distance) : the remainder (obtained) after substraction denotes the Sun's true declination. The Sun is also, in that case, undoubtedly in the southern hemisphere.

A rule for the determination of the sun's longitude from its declination :

16. The radius multiplied by the Rsine of that (Sun's declination) should be divided by the Rsine of the Sun's greatest declination. The resulting Rsine reduced to arc, or ($90^0$ minus that arc) increased by three signs, or that (arc) increased by six signs, or ($90^0$ minus that arc) increased by nine signs, according as the Sun is in the first, second, third, or fourth quadrant, is the Sun's longitude.

The longitude thus obtained is *sayana.*

In the above rule a knowledge of the Sun's quadrant is assumed, but nowhere in the present work are we told how to know the Sun's quadrant. From other works on Indian astronomy we learn that it was known from the nature of the midday shadow. In the *Pitamaha-siddhanta* we are given the following criteria for knowing whether the Sun is in the first, second, third, or fourth quadrant :

"(When the Sun is) in the first quadrant, the (midday) shadow of the trees is smaller than the equinoctial midday shadow and also decreasing (day to day); in the second quadrant, it is in smaller (than the same) but increasing; in the third quadrant, it is greater and also increasing ; and in the fourth, it is greater but decreasing".

So also says Sripati, but (for places below the tropic of cancer) he adds :

"If the (midday) shadow fall towards the south and be on the increase, even then the quadrant is the first. Similarly, if you see that the (midday) shadow (falling towards the south) is on the decrease, you must understand that the quadrant is the second".

A rule for the determination of the latitude with the help of the Sun's meridian zenith distance and declination :

17. When the Sun is in the northern hemisphere (and the shadow of the gnomon falls towards the north) add the (Sun's) declination and the (Sun's) meridian zenith distance; when the Sun is in the southern hemisphere, or

when the (midday) shadow (of the gnomon) falls towards the south (of the gnomon) take their difference: the sum or difference thus obtained is the latitude.

A rule for finding the Rsine of the Sun's altitude or zenith distance from the time elapsed since sunrise in the forenoon or from the time to elapse before sunset in the afternoon:

18-20. Add the (Sun's) ascensional difference derived from the local latitude to or substract that from the asus (elapsed since sunrise in the forenoon or to elapse before sunset in the afternoon) according as the Sun is in the southern or northern hemisphere. By the Rsine of that (sum or difference) multiply the day-radius and then divide (the product) by the radius. In the resulting quantity apply the earthsine reversely to the application of the ascensional difference (i.e., substract the earthsine when the Sun is in the southern hemisphere and add the earthsine when the Sun is in the northern hemisphere). Then multiply that (i.e., the resulting difference or sum) by the Rsine of the Colatitude of the local place and then divide (the product) by the radius again. Thus is obtained the Rsine of the Sun's altitude for the given time in ghatis. The square root of the difference between the squares of the radius and that (Rsine of the Sun's altitude) is known as the (great) shadow.

An approximate rule for finding the sun's altitude :

21. Multiply "the upright due to the instantaneous meridian-ecliptic point" by the Rsine of the degrees intervening between the Sun and the rising point of the ecliptic and then divide (the product) by the radius : the result is the Rsine of the Sun's true altitude. The square root of the difference between the squares of that and the radius is the Rsine of the Sun's zenith distance.

Definition of "the upright due to the meridian-ecliptic point :"

22. The square root of the difference between the squares of the Rsine of the zenith distance of the meridian-ecliptic point and of the radius (*ravi-kaksya*) is called " the upright due to the meridian-ecliptic point" by those who are well versed in spherics.

Thus we see that " the upright due to the meridian-ecliptic point" is the Rsine of the altitude of the meridian-ecliptic point. It is usually called *madhya-sanku.*

Two alternative rules for finding the Sun's altitude :

23-24. Increase or diminish the ghatis (elapsed since sunrise in the fore noon or to elapse before sunset in the afternoon) by the asus of the (Sun's) ascensional difference (according as the Sun is in the southern or northern hemisphere). To the Rsine of that apply the Rsine of the (Sun's) ascensional difference reversely to the above. By what is thus obtained multiply the product of the day-radius and (the Rsine of) the colatitude and then divide (the

resulting product) by the square of the radius. The result of this (operation) is the Rsine of the (Sun's) altitude.

Or, multiply the result obtained by the inverse application of Rsine of the (Sun's) ascensional difference (in the above process) by the product of (the length of) the gnomon and the day-radius and then divide by the product of (the length of the hypotenuse of the equinoctial midday shadow and the radius; the result is the Rsine of the (Sun's) altitude.

A rule for finding the Sun's altitude when the Sun's ascensional difference is greater than the given time :

25. When the (Sun's) ascensional difference (is greater than and) cannot be substracted from the given asus (elapsed since sunrise in the forenoon or to elapse before sunset inthe afternoon), substract the latter from the former and with the Rsine of the remainder proceed as before (i.e., multiply that by the day-radius and divide by the radius); then subtract the resulting Rsine from the earthsine and then performing the usual process (i.e., multiplying that by the Rsine of the colatitude and dividing the product by the radius) determine the Rsine of the (Sun's) altitude.

A rule for finding the Sun's altitude in the night :

26. In the night, the Rsine of the Sun's altitude is to be obtained by applying the operations (of addition and subtraction) inversely, because the (laws of ) addition and subtraction (of the Sun's ascensional difference and earthsine) in the night are contrary to those in the day.

27-29. Multiply the Rsine of the Sun's altitude derived from the given shadow (of the gnomon) by the radius and divide (the product) by (the Rsine of ) the colatitude. Then subtract the minutes of the earthsine from or add them to the resulting quantity according as the Sun is in the six signs begining with Aries or in the southern hemisphere. Multiply the resulting quantity by the radius and divide (the product) by the day-radius. To the corresponding arc apply the ascensional difference contrarily to the above: thus is obtained the number of asus (elapsed since sunrise in the forenoon or to elapse before sunset in the afternoon). These very same asus corresponding to the day to elapse ( before sunset in the afternoon) or the day elapsed (since sunrise in the forenoon), when divided by 360, are declared to be the *nadis*, etc.,(of the required time).

Or, multiply the given Rsine of the Sun's altitude by the square of the radius and divide by the product of the day-radius and (the Rsine of) the colatitude. To the result apply the Rsine of the (Sun's) ascensional difference as before (i.e., subtract or add according as the Sun is in the northern or southern hemisphere). Then to the corresponding arc reversely apply the asus of the

ascenaional difference : the result obtained is again the number of asus (elapsed since sunrise in the forenoon or to elapse before sunset in the afternoon.)

Or, multiply the Rsine of the Sun's altitude by the hypotenuse of the equinoctial midday shadow and again by the radius and then divide (the resulting product) by the day-radius as multiplied by (the length of) the gnomon. From that the process for the determination of the (desired time in) *nadis* is the same as before.

The first rule is the converse of the rule given in stanzas 18-20; the second rule is the converse of that given in stanza 23; and the third rule is the converse of that stated in stanza 24.

A rule for finding the longitude of the rising point of the ecliptic with the help of (i) the instantaneous sayana longitude of the Sun and (ii) the civil time measured since sunrise, or with the help of (i) the Sun's sayana longitude at sunrise and (ii) the sidereal time elapsed since sunrise.

30-32. Multiply by the untraversed portion of (the sign occupied by) the Sun, the asus of the oblique ascension (i.e., the time, in asus, of rising at the local place) of that sign and divide (that product) by the number of degrees or minutes in a sign (i.e., by30 0r 1800) (according as the untraversed portion of the Sun's sign is taken in degrees or minutes). Thus are obtained the asus of the oblique ascension of the untraversed portion of the sign occupied by the Sun. Subtract these from the given (time as reduced to ) asus; and add the untraversed portion of the Sun's sine to the Sun's longitude (which is given). Then from the remaining asus subtract the asus of the oblique ascension of as many (suceeding) signs as possible; and add the same number of signs to the Sun's longitude. Then multiply the outstanding residue of the given (time in) asus by 30 and divide (the product) by the asus of the oblique ascension of the next sign. Add the resulting degrees, etc., to the Sun's longitude (obtained above). The resulting longitude is stated to be the (sayana) longitude of the rising point of the ecliptic.

A rule for the determination of the longitude of the setting point of the ecliptic :

33. The longitude of the horizon-ecliptic point in the east increased by half a circle (i.e., by $180^0$ ) is the longitude of the setting point of the ecliptic. For, the time of setting of a sign is equal to the time taken in rising by then rising sign.

34-36. Multiply the degrees of the traversed portion of the sign occupied by the rising point of the ecliptic by the oblique ascension of that sign and divide by 30, the resulting asus denote the asus of the oblique ascension of the traversed portion of the sign occupied by the rising point of the ecliptic. (Also subtract the traversed portion of the sign occupied by the rising point of the ecliptic from the longitude of the same point). Then from the resulting longitude subtract as many preceding signs as there are up to the Sun; and find out the

asus of the oblique ascensions of those signs. These *asus* together with those (obtained above) when added with the *asus* of the oblique ascension of the untraversed portion of the Sun's sign give the asus (elapsed since sunrise) in the day and (enable us to know) the asus (elapsed since sunset) in the night. Dividing them by 6 and then by 60 are obtained the *ghatis*, *vighatis*, and *asus* (of the time elapsed during the day or night).

A rule for the determination of the Rsines of the Sun's prime vertical altitude and zenith distance :

37-38. Multiply the Rsine of the (Sun's) greatest declination by the Rsine of the Sun's true (*sayana*) longitude; then divide (the product) by the Rsine of the colatitude : the result is (the Rsine of) the agra of the true Sun. When that (agra) is less than the latitude and when the Sun is also in the northern hemisphere, multiply ( the Rsine of the Sun's agra) by (the Rsine of ) the colatitude and then divide (the product) by the Rsine of the latitude : the result is the Rsine of the Sun's prime vertical altitude. The square root of the difference between the squares of that and radius is the Rsine of the Sun's (prime vertical) zenith distance.

A rule for the determination of the time in asus to elapse before or elapsed since midday when the Sun is on the prime vertical, i.e., the time taken by the Sun in going from the prime vertical to the local meridian or *vice versa* :

39. Multiply the Rsine of the Sun's longitude (when the Sun is on the prime vertical) by the Rsine of the (Sun's)

Greatest declination and divide (the product) by the day-radius: by the result obtained multiply the Rsine of the colatitude and (then) divide by the Rsine of the latitude. Subtract the square of the resulting quantity from the square of the radius: these are corresponding to the square root of that gives the asus (measured on the equator from the Sun's hour circle) up to the meridian.

An alternative rule :

40. Or, multiply the Rsine of the Sun's prime vertical zenith distance by the radius and divide by the day-radius. Then applying the method of finding out the arc (corresponding to a given Rsine), convert the resulting rsine into (the corresponding)arc. Then reduce the asus (thus obtained) to *nadis*, etc. These lie between the (prime vertical) Sun and the meridian.

A rule for finding the Sun's longitude when the Sun is on the prime vertical :

41. Multiply the Rsine of the latitude by the Rsine of the prime vertical altitude derived from the shadow (of the gnomon) and always divide the product by the Rsine of the Sun's greatest declination ( then reduce the resulting Rsine to the

corresponding arc ). The arc thus obtained, or ( the complement of ) that are increased by three signs is the longitude of the (prime vertical) Sun (according as the Sun is in the first or the second quadrant). This is in accordance with what (Arya)bhata has written.

To determine at any given time points lying on the locus of the shadow-end :

42-45 Determine the agra and sankvagra of the Sun and also the shadow ( of the gnomon) for desired time. Then take the sum of the two agras (i.e., of agra and sankvagra) provided that they are of like direction; in the contrary case, take their difference. (This sum or difference is called bhuja and its direction corresponds to that of the sun from the prime vertical ). By that ( sum or difference) multiply the shadow and divide (the product) by the Rsine of the Sun's zenith distance (for that time). Whatever is thus obtained should be laid off from the centre in the contrary direction (i.e., contrary to the direction of the Sun from the prime vertical) within a circle ( drawn on level ground and ) marked with the directions. Through the fish-figure drawn about the point thus obtained stretch out a thread in the east and west directions (bothways ) to a distance. Then take a thread equal in length to the shadow (of the gnomon) and lay it off from the centre obliquely ( to meet the other thread). Mark the two points where the end of this thread meets (the other thread stretched out ) in the east and west directions. At the end of the midday shadow take a third point.

A rule for determining the same three points when the directions are not known :

46-51. For one who does not know the directions with regard to the centre but wants to determine the directions and locus of (the end of ) the shadow (of the gnomon), state the method such that (the end of ) the shadow (of the gnomon) may not leave the periphery of the large circle distinctly drawn amidst the directions (representing the path of the shadow-end).

Calculate the Rsine of the Sun's zenith distance, the Rsine of the sun's altitude, and the sankvagra corresponding to the desired shadow ; then take the difference or sum of the two agras (i.e., of the sankvagra and the agra) (according as they are of unlike or like directions). This (difference or sum) is the base, the Rsine of the Sun's zenith distance is the hypotenuse, and the square root of the difference between their squares is called the upright corresponding to the hypotenuse equal to the Rsine of the Sun's zenith distance . On multiplying these, upright and base (severally) by the (length of the ) shadow and dividing by the Rsine of the sun's zenith distance are obtained the values of the upright and the base (corresponding to the hypotenuse equal to the shadow of the gnomon). Now take straight bamboo scales of breadth equal to the diameter of the gnomon and lengths equal to the base and upright (obtained above) (and one equal to the shadow); and with their help construct an accurate framework instrument in the form of a rectangle or a (right-angled) triangle having the shadow (of the gnomon) for the

hypotenuse. At the corner (where the base and the hypotenuse meet) fix a gnomon. Then put the instrument (on level ground) and rotate it (about the gnomon) until the shadow (of the gnomon) falls along the hypotenuse Then having determined the directions (north and south, east and west) as indicated by the base and the upright , mark two points at the end of the shadow-hypotenuse (one towards the east and the other towards the west). A the end of the midday shadow, take the third point.

Construction of the locus of the end of the shadow of a gnomon :

52. Through all the three points (thus obtained) a circle is (then) drawn with the help of two fish-figures. The shadow (of the gnomon) moves like a spell-bound serpent with its head (i.e.,end) kept upon the periphery of that circle.

Alternative rules for finding the Sun's agra and the latitude of the place :

53. The squareroot of the sum of the squares of the Rsine of the (Sun's) declination and the earthsine for the desired time is (the Rsine of ) the Sun's agra (for that time).

The earthsine multiplied by the radius and divided by (the Rsine of) the Sun's agra is the Rsine of the latitude.

These results easily follow from the triangle.

A rule for the determination of the sankvagra :

54. The Rsine of the altitude for the desired time multiplied by the Rsine of the latitude and divided by (the Rsine of ) the colatitude is the sankvagra, which is always south (of the rising-setting line)

The sankvagra (of a heavenly body) is the distance of the projection of the heavenly body on the plane of the horizon from its rising-setting line. The sankvagra is measured from the rising-setting line and is always to the south of that line. It is more commonly known as sankutala.

A rule for finding the equinoctial midday shadow :

55. Multiply the sankvagra by 12 and divide by the Rsine of the altitude : the result is (the length of) the equinoctial

Method of Finding the Sun's agra by observation and Deriving there from the sankvagra and then the equinoctial midday shadow of the gnomon and the latitude or colatitude of the place:

56-60(i) One should erect a (circular) platform, as high as one's neck, with its floor in the same level, and its circumference graduated with the divisions of signs, degrees, etc., and bearing the marks of the directions. (Then standing ) on the western side thereof, one, having undisturbed state of mind , should, with the line of sight passing through the centre of the circular base, make the observation of the Sun when (at sunrise) it appears Clinging ti the curcumference, (and mark there a point). The (arcual) distance, measured along the curcumference graduated with the marks of degrees, between the end

of the line drawn eastwards (i.e., the east point) and the where the Sun is observed is the arc of the Sun's *agra*. The Rsine of that (arc) is (the Rsine of ) the Sun's agra. The minutes of the difference between that (Rsine of the Sun's agra) and the Rsine of the Sun's meridian zenith distance are the minutes of the sankvagra, provided that the Sun is in the southern hemisphere; when the Sun is in the northern hemisphere (and the shadow of the gnomon falls towards the north), the process is otherwise (i.e., the addition of the two). When, however, (the sun being in the northern hemisphere) the shadow (of the gnomon) due to the Sun falls towards the south, the Sun's agra minus the Rsine of the Sun's meridian zenith distance is stated to be (the value of ) the sankvagra. From that (sankvagra) determine the true value of the equinoctial midday shadow (of the gnomon), and then calculate as before the latitude and colatitude (for the place).

A rule for finding the longitude of an unknown planet with the help of (i) the longitude of a known planet and (ii) the difference between the times of rising or setting of the known and unknown planets :

60(ii)-61. Having correctly ascertained in terms of nadikas (i.e., ghatis) the difference between (the times of rising or setting or culmination of ) the planets to be known multiply those ghatis by six. Thus are obtained the degrees (of the difference between the longitudes of the two planets). By those degrees diminish or increase the longitude of the known planet according as it is to the east or west of the planet to be known. This is stated by the learned people well versed in planetary motions (to be the method for getting the longitude of the planet to be known).

(2) JUNCTION-STARS OF THE ZODIACAL ASTERISMS AND CONJUNCTION OF PLANETS WITH THEM.

Longitudes of the prominent stars of the naksatras:

62. In this way from ( the known longitudes of ) the planets or stars have been determined, at all times, the celestial longitudes of the (prominent) stars of the naksatras.

**Names, Shapes, and Number of the Stars of the *Naksatras***

Name Shape Number of stars Identification

as given by

Asvini Head of a horse 3 2 3 Ariet is

| | | | | | |
|---|---|---|---|---|---|
| Bharani | Yoni | 3 | 3 | 3 | 35,39,41 Ariet is |
| Krttika | Razor | 6 | 6 | 6 | Tauri, etc. (Pleiades) |
| Rohini | Cart (Hyades) | 5 | 5 | 5 | □̃□̣□̣□̣Tauri |
| Mrgasira | Head of a deer | 3 | 3 | 3 | □,□1,□2 Orionis |
| Ardra | Jewel | 1 | 1 | 1 | □̣Orionis |
| Punarvasu | House | 5 | 2 | 4 | □̤□̣i,□̣□̣Geminorum |
| Pusya | Arrow-head | 3 | 1 | 3 | □̤□̤□̣Cancri |
| Aslesa | Wheel | 6 | 6 | 5 | □̤□̣□̣□̣□̣Hydrae |
| Magha | House | 5 | 6 | 5 | □̤□̤□,□̤□̤□̣Leonis |
| Purva Phalguni | Manca | 8 | 2 | 2 | □̤□̣Leonis |
| Uttra Phalguni | Cot | 2 | 2 | 2 | □̤□□̣Leonis |
| Hasta | Hand (Corvus | 5 | 5 | 5 | □̤□̤□̤□̤□̣Corvi |

| Name | Shape | Number of stars as given by | | | Identification |
|---|---|---|---|---|---|
| Citra | Pearl | 1 | 1 | 1 | □̣Virginis (Spica) |

| | | | | | |
|---|---|---|---|---|---|
| Svati | Coral bead | 1 | 1 | 1 | □Bootis (Arcturus) |
| Visakha | An arched doorway | 5 | 2 | 4 | *i,* □□□ Librae |
| Anuradha | Heaps of offering to gods | 4 | 4 | 4 | □□□Scorpionis |
| Jyestha | Earpendant | 3 | 3 | 3 | □□□Scorpionis |
| Mula | Tail of a lion | 11 | 2 | 11 | □□□□□□□□□ Scorpionis |
| Purva - sadha | Tusk of an elephant | 2 | 4 | 2 | □□Sagittarii |
| Uttara- sadha | Manca | 3 | 4 | 2 | □□Sagittarii |
| sravana | Three feet | 3 | 3 | 3 | □ □□Aquilae |
| Dhanistha | Drum | 5 | 5 | 4 | □□□□Leonis |
| Satabhisak | Circle | 100 | 1 | 100 | □Aquarii, etc. |
| Purva Bhadrapada | Manca | 2 | 2 | 2 | □□Pegasi |
| Uttara- Bhadrapada | Pair | 8 | 2 | 2 | □Pegasi, □ Andromedae |
| Revati | Drum | 32 | 1 | 32 | □Piscium, etc. |



Position of the junction-stars of the asterisms (naksatras) in the twelve signs, Aries, etc:

63-66 (i) In Aries, eight, twenty-seven; in Taurus, six, nineteen; in Gemini, two, ten; in the next sign (i.e., Cancer), two, fifteen, twenty-four; in Leo, eight and a half, twenty-one; in Virgo, four, twenty-three; in Libra, five, seventeen; in the next sign (i.e., Scorpio), two, twelve, eighteen; in Sagittarius, one, fourteen, twenty-seven; in Capricorn, fifteen, twenty-siz; in Aqurius, seven, twenty-eight;

in the last sign (i.e., Pisces), fifteen, thirty-these are the degrees of the positions (with reference to the signs) of the junction-stars of the *naksatras* beginning with Asvini.

The prominent stars of the naksatras which were used in the study of the conjunction of the planets, especially the Moon, with them are called junction-stars (yoga-tara). The study of the conjuction of the planets with the junction-stars was originally meant to verify the computed longitudes of the planets with a view to test the assuracy of and to make improvements, if necessary, in the astronomical theories on which those computations were based.

The longitudes of the junction-stars which have been enumerated in the text are, in some cases, slightly at variance with those given by the author in his subsequent smaller work, the *Laghu-Bhaskariya*. The differences are exhibited by the following table:

**Difference between the Longitudes of the Junction-Stars in the Two Works of Bhaskara I**

| Junction-stars of | Longitude given in Maha-Bhaskariya | Longitude given in Laghu Bhaskariya | Difference |
|---|---|---|---|
| Asvini | 8 | 8 | |
| Bharani | 27 | 26 30 | -30 |
| Kartika | 1$^s$ 6 | 1$^s$ 6 | |
| Rohini | 1$^s$ 19 | 1$^s$ 20 | 1 |
| Mrgasira | 2$^s$ 2 | 2$^s$ 2 | |
| Ardra | | 2$^s$ 10 | 2$^s$ 10 |
| Punarvasu | 3$^s$ 2 | 3$^s$ 2 | |
| Pusya | 3$^s$ 15 | 3$^s$ 15 | |
| Aslesa | 3$^s$ 24 | 3$^s$ 24 | |
| Mugha | 4$^s$ 8 | 4$^s$ 8 | |
| Purva Phlaguni | 4$^s$ 21 | 4$^s$ 21 | |
| Uttara Phalguni | 5$^s$ 4 | 5$^s$ 4 | |
| Hasta | 5$^s$ 23 | 5$^s$ 23 | |
| Citra | | 6$^s$ 5 | 6$^s$ 5 |
| Svati | | 6$^s$ 17 | 6$^s$ 17 |

| | | | | |
|---|---|---|---|---|
| Visakha | 7$^{s}$ 2□ | 7$^{s}$ 2□ | | |
| Anuradha | 7$^{s}$ 12□ | 7$^{s}$ 12□ | | |
| Jyestha | 7$^{s}$ 18□ | 7$^{s}$ 18□ | | |
| Mula | | 8$^{s}$ 1□ | 8$^{s}$ 1□□□ | □□ |
| Purvasadha | 8$^{s}$ 14□ | 8$^{s}$ 14□□□ | □□ | |
| Uttarasadha | 4$^{s}$ 27□ | 8$^{s}$ 26□□□ | □□ | |

Junction-stars ofLongitude according to(Polar) longi tude according to

| | MBh | LBh | SiDVr | SuSi | BrSpSi,SiSe, SiSi | |
|---|---|---|---|---|---|---|
| Pusya | 105□ | 105□ | 105□ | 106□ | 106□ | |
| Aslesa | 114□ | 114□ | 114□ | 109□ | 108□ | |
| Magha | 128 □30□ | 128□ 30□ | | 128□ | 129□ | 129□ |
| Purva Phalguni | | 141□ | 141□ | 139 □20□ | 144□ | 147□ |
| Uttara Phalguni | | 154□ | 154□ | 154□ | 155□ | 155□ |
| Hasta | 173□ | 173□ | 173□ | 170□ | 170□ | |
| Citra | | 185□ | 185□ | 184 □20 | 190□ | 185□ |
| Svati | | 197□ | 197□ | 197□ | 199□ | 199□ |
| Visakha | 212□ | 212□ | 212□ | 213□ | 212□ 5□ | |
| Anuradha | 222□ | 222□ | 222□ | 224□ | 224 □5□ | |
| Jyestha | 228□ | 228□ | 228□ | 229□ | 229 □5□ | |
| Mula | | 241□ | 241□ 30□ | 241□ | 241□ | 241□ |
| Purvasadha | 254□ | 254□ 30□ | 254□ | 254□ | 254□ | |
| Uttarasadha | 267□ | 266□ 30□ | 267□ 20□ | 260□ | 260□ | |
| Sravana | 285□ | 284□ 30□ | 283□ 10□ | 280□ | 278□ | |
| Dhanistha | 269□ | 295□ 30□ | 296□ 20□ | 290□ | 290□ | |
| Satabhisak | 307□ | 307□ | 313□ 20□ | 320□ | 320□ | |
| Purva-Bhadrapada | | 328□ | 328□ | 327□ | 326□ | 326□ |

| | | | | | | |
|---|---|---|---|---|---|---|
| Uttara-Bhadrapada | 345□ | 345□ | 335□ 20□ | 337□ | 337□ | |
| Revati | 360□ | 360□ | 359□ | 359□ 50□ | 0 | |

Celestial latitudes of the junction-stars, definition of the conjuction of a planet with a star, and a rule for determining the distance between a planet and a star when they are in conjuction.

66. (ii)- 71(i). North, ten, twelve, five; south, five, ten, eleven; north, six, zero, south, seven, zero; north, twelve, thirteen; south, seven, two; north, thirty-seven; south, one and a half, three, four, eight plus one-third, seven, seven plus one third; north, thirty, thiry-six, zero-these have been stated by the learned to be the celestial latitudes of the junction stars of the naksatras beginning with Asvini.

All planets having their longitudes equal to those of the junction-stars are seen in conjunction with them.

The distance between a planet and a star (when they are in conjunction) is determined from their celestial latitudes.

The celstial latitudes of the junction-stars stated above are exhibted in the following table. We also give the celestial latitudes stated in the other important works on Hindu astronomy.

| Junction-stars of | Longitude according to | | | (Polar) longitude according to | | |
|---|---|---|---|---|---|---|
| | MBh | LBh | SiDVr | SuSi | BrSpSi,SiSi | |
| Asvini | 10□ N | 10□ N | 10□ N | 10□ N | 10□ N | 10□ N |
| Bharani | 12□ N | 12□ N | 12□ N | 12□ N | 12□ N | 12□ N |
| Kartika | 5 □N | 5□ N | 5□ N | 5□ N | 4□ 31□ N | 4□ 30□ N |
| Rohini | 5 □S | 5□ S | 5□ S | 5 □S | 4□ 33□ S | 4□ 30□ S |
| Mrgasira | 10□ S | 10□ S | 10□ S | 10□ S | 10□ S | 10□ S |
| Ardra | | 11□ S | 11□ S | 11□S | 9□ S | 11□S | 11□S |
| Punarvasu | 6□ N | 6□ N | 6□ N | 6□ N | 6□ N | 6□ N |
| Pusya | 0 | 0 | 0 | 0 | 0 | 0 |
| Aslesa | 7□ S | 7□ S | 7□ S | 7□ S | 7□ S | 7□ S |

| | | | | | | |
|---|---|---|---|---|---|---|
| Mugha | 0 | 0 | 0 | 0 | 0 | 0 |
| Purva Phlaguni | 12□ N | 12□ N | 12□ N | 12□ N | 12□ N | 12 □N |
| Uttara Phalguni | 13□ N | 13□ N | 13□ N | 13□ N | 13□ N | 13 □N |
| Hasta | 7□ | 7□ | 8□ S | 11□ S | 11□ S | 11□S |
| Citra | 2□ S | 2□ S | 2□ S | 2□ S | 1□45□S | 1□ 45□ S |
| Svati | 37□ N | 37□N | 37□N | 37□N | 37□N | 37□N |
| Visakha | 1□ 30□ S | 1□ 30□ S | 1□ 30□ S | 1□ 30□ S | 1□ 23□ S | 1□ 20□ S |
| Anuradha | 3□ S | 3□ S | 3□ S | 3□ S | 1□ 44□ S | 1□ 45□ S |
| Jyestha | 4□ S | 4□ S | 4□ S | 4□ S | 3□ 30□ S | 3□ 30□ S |
| Mula | 8□ 20□ S | 8□ 30□ S | 8□ 30□ S | 9□ S | 8□ 30□ S | 8□ 30□ S |
| Purvasadha | 7□ S | 7□ S | 5□ 20□ S | 5□ 30□ S | 5□ 20□ S | 5□ 20□ S |
| Uttarasadha | 7□ 20□ S | 7□ s | 5□ S | 5□ S | 5□ S | 5□ S |

| Junction | Latitude Give in MBh | LBh | SiDVr | (Polar) latitude give in SuSi | BrSp Si KK, SiSe | SiSi |
|---|---|---|---|---|---|---|
| Sravana | 30□ N | 30□ N | 30□ N | 30□ N | 30□ N | 30□ N |
| Dhanistha | 36□ N | 36□ N | 36□ N | 36□ N | 36□ N | 36□ N |
| Satabhisak | 18 S | 18 S | 20 S | 30 S | 18 S | 20 S |
| Purva-Bhadra pada | 24□ N | 24□ N | 24□ N | 24□ N | 24□ N | 24□ N |
| Uttara- Bhadra pads | 26□ N | 26□ N | 26□ N | 26□ N | 26□ N | 26□ N |
| Revati | 0 | 0 | 0 | 0 | 0 | 0 |

Clestial latitudes of the Moon when she occults some of the prominent stars of the zodiac:

71 (ii) - 75 (i) It is stated that the Moon, moving towards the south of the ecliptic, obliterates (i.e. occults) the cart of Rohini (i.e. the constellation of

Hyades), when her latitude amounts to 60 minutes; the junction-star (of Rohini) i.e. Aldebaran), when her latitude amounts to 256 minutes; (the junction star of) Citra (i.e., Spica), when her latitude amounts to 95 minutes; (the junction-star of) Jyestha (i.e. Antares), when her latitude amounts to 200 minutes; (the junction-star of) Anuradha when her latitude amounts to 150 minutes; the junction-star of) Satabhisak (i.e. Aquarii), when her latitude amounts to 24 minutes; (the junction-star of) Visakha, when her latitude amounts to 88 minutes; and )the junction-star of) Revati (□piscium), when her latitude vanishes. When she moves towards the north (of the ecliptic), she occults the nakshtra Krittika (i.e., the Pleiades), when her latitude amounts to 160 minutes; and the central star of the nakshtra Magha, when she assumes the greatest northern latitude. These minutes (of the Moon's latitude) which have been stated (here) in connection with the occultation of a star by the planet (Moon) are based on actual observation made by means of instrument (called) Yasti.

## CHAPTER IV

## TRUE LONGITUDE OF A PLANET

**Definition of the Sun's mean anomaly :**

1. Having applied the correction for the (local) longitude to the mean longitude of the Sun, subtract (there from) the longitude of the Sun's apogee (ucca): the remainder is the Sun's (mean) anomaly. In that (anomaly), three signs form a quadrant.

A rule relating to the Rsine of the Sun's mean anomaly:

2. (Of the parts of the Sun's mean anomaly lying) in the odd quadrants, calculate the Rsine; and (of the parts lying) in the even quadrants, calculate the Reversed-sine. The method for finding the Rsines (i.e., Rsines and Reversed-sines) is being told in detail (below).

For example, if the Sun's mean anomaly is $140^0$, calculate the Rsine of $90^0$ and the Reversed-sine of $50^0$, if the Sun's mean anomaly is $240^0$, calculate the Rsine of $90^0$, the Reversed-sine of $90^0$, and the Rsine of $60^0$, and if the Sun's mean anomaly be $300^0$, calculate the Rsine of $90^0$, the Reversed-sine of $90^0$, again the Rsine of $90^0$ and the Rversed-sine of $30^0$.

The above passage shows that in the time of Bhaskara I one of the methods used for finding the Rsine of an arc (>$90^0$) was to apply the following formulae :

Rsin ($90^0$ + □) = Rsin $90^0$- Rversin □.

Rsin ($180^0$+□) = Rsine $90^0$-Rversin$90^0$-Rsin □

. ̣□Rsin □̃

Rsin ($270^0$ + ̣̣̣□̣□ Rsine $90^0$ - Rversin $90^0$ - Rsin $90^0$ + Rversin □

= - Rsin $90^0$ + Rversin □ ,

where □ < $90^0$

A rule for finding the Rsine (or Rversed-sine) of an arc (<$90^0$) :

3-4 (i). Reduce the arc to minutes and then divide by 225 : the quotient denotes the number of (tabulated) Rsine-differences (or Rversed-sine-differences) to be taken completely. Then multiply the remainder by the next (or current) Rsine-difference (or Rversed-sine-difference) and divide (the product) by 225. Add the quotient (thus obtained) to the sum of the (tabulated) Rsine-differences (or Reversed-sine-differences)obtained before. The sum thus obtained is the Rsine (or Reversed-sine) of the given arc.

This rule gives a method for calculating the Rsine or Reversed-sine of an arc by the help of the following table of Rsine-differences given by Aryabhatiya.

The method for calculating the Rsine or Rversed-sine of an arc, as stated in the text, may be explained by means of an example as follows:

Example. Calculate Rsin $32^0$ and Rversin $32^0$.

Reducing 32 degrees to minutes, we get 1920'. Dividing this by 225, we get 8 as the quotient and 120 as the remainder.

(1) The sum of the first 8 Rsine-differences is 1719'. Multiplying the remainder 120 by the 9th Rsine-difference (viz. 191') and dividing the product by 225, we get 101' 52". Adding this to the previous sum, we get 1820' 52" or 1821' approx. This is the value of Rsin $32^0$.

(2) The sum of the first 8 Rversed-sine-differences is 460'. Multiplying the remainder 120 by the 9th Rversed-sine-difference (viz.119') and dividing that product by 225, we get 63' 28". Adding this to the previous sum, we get 523' 28" or 523' approx. This is the value of Rversin $32^0$.[1]

The above method for finding the Rsine of a given arc is evidently based on the simplest law of interpolation, viz. that of proportion. In later works, we come across more elegant methods of interpolation. We state here two of them.

**1. Brahmagupta's formula.**

If < 225' and t be an integer, then

Rsin (225't +' ) = sum of t Rsine-differences

+ {$t^{th}$ Rsine-diff. + $(t+1)^{th}$ Rsine-diff.

225 2

- {$t^{th}$ Rsine-diff. - $(t+1)^{th}$ Rsine-diff./ 2} (1)

225 2

= sum of t Rsine-differences

+ {$(t+1)^{th}$ Rsine-difference}

225

+ 1 . .(-1){$(t+1)^{th}$ Rsine-difference

2 225 225

-$t^{th}$ Rsine-difference}.(2)

Using modern four-figure tables and assuming that one radian = 206265", we get Rsine $32^0$ = $30^0$ 21' 43" approx. and Rversin $32^0$=$8^0$ 42' 22" approx. This shows that the values derived from Aryabhata I's table give fairly good approximations to the Rsines and Rversed-sines up to minutes of arc.

Form (1) occurs in P.C. Sengupta's edition of the Khandakhadyaka of Brahmagupta and also in the Siddhanta-siromani of Bhaskara II. Form (2) is found to occur in Paramesvara's commentry on the Laghu-Bhaskariya. This formula agrees with Newton's interpolation formula for equidistant knots.

**2. Madhava's formula.**

If t be a positive integer and 0<225, then

Rsin (225 t + 0) = sum of t Rsine - differences

+ 0 x [Rcos {225 (t + 1)} + R cos (225t)]

2 R

This formula is ascribed to Madhava by Nilakantha in his commentary on the Aryabhatiya. It occurs also in the Tantra-sangraha.

In Chapter VII of the present work, Bhaskara I gives a very interesting method for finding the Rsine of a given arc without the use of a table.

A rule for finding the Sun's equation of the centre:

4 (ii) . The Rsines and R versed-sine (of the parts of the Sun's mean anomaly lying in the odd and even quadrants respectively) should be (severally) multiplied by the (Sun's) own epicycle and divided by 80: the resulting quantites should be subtracted and added (in the manner prescribed below)

Application of the Sun's equation of the centre :

5. The resulting quantities due to the first, second, third and fourth anomalistic quadrants should always be respectively subtracted from, added to, and subtracted from the Sun's mean longitude corrected for the (local) longitude.

Alternative rule for the determination and application of the Sun's equation of the centre (called bahuphala):

6. Or, (find the *bahuphala* and) subtract the *bahuphala* when the (Sun's mean) anomaly is in the half-orbit beginning with Aries; and add that when (the Sun's mean anomaly is) in the half-orbit beginning with Libra. This correction should always be performed by one who seeks the true longitude (of the Sun)

7. Multiply the mean daily motion (of the Sun) by the (Sun's) equation (of the centre derived from the R sines and Rversed-sines of the parts of the Sun's mean anomaly lying in the odd and even quadrants respectively) or by the (Sun's) *bahuphala* (i.e., the Sun's equation of the centre derived from the bahu) and then divide the product by the number of minutes in a circle (i.e. by 21600); apply that (as correction, positive or negative, to the Sun's mean longitude corrected for the local longitude and for the Sun's equation of the centre) as before.

The *bhujantra* correction is the third correction to be applied to the Sun's mean longitude. By this correction "allowance is made for that part of the equation of time, or of the difference between mean and apparent solar time, which is due to the difference between the Sun's mean and true places". This correction having been applied to the Sun's longitude, we obtain the Sun's true longitude for true sunrise at the *svaniraksa* place.

Definitions of the *bahu* and *koti* (due to a planet's mean anomaly)

8. The portions (of the mean anomalistic quadrant) traversed and to be traversed (by a planet) are called *bahu* and *koti* or *koli* and *bahu*, according as the mean anomalistic quadrant (occupied by the planet) is odd or even. The

*bahuphala* and *kotiphala* are obtained as before for the determination of the hypotenuse (i.e. the distance of the planet).

A rule for the determination of the true distance in minutes of the Sun or Moon:

9-12. (When the Sun or Moon is ) in the first or fourth (mean anomalistic) quadrant, add the *kotiphala* to the radius; (When) in the remaining (quadrants), subtract that from the radius: the resulting sum of difference is the upright. The square root of the sum of the squares of that and the *bahuphala* is called the hypotenuse. Multiply that hypotenuse (severally) by the *bahuphala* and kotiphala and divide (each product) by the radius: the results are (again) the *bahuphala* and *koliphala*. From them obtain the *hypotenuse* (again) as before. Again multiply this hypotenuse (severally) by the initial *bahuphala* and joliphala and divide (each product) by the radius. In this way, proceeding as above, obtain the hypotenuse again and again until two successive values of the hypotenuse agree (to minutes). (Thus is obtained by nearest approximation to the true distance in minutes of the Sun or Moon).

A rule finding the true daily motion (called karnabhukti) of the Sun or Moon:

13. Always multiply the (mean) daily motion of the Sun or Moon by the radius and (then) divide (the product) by the hypotenuse (i.e. the true distance) determined by the method of successive approximations; the result is the true daily motion (of the Sun or Moon).

A rule for finding the true daily motion (called *jivabhukti*) of the Sun:

14. Or, multiply the current Rsine difference by the (mean) daily motion (of the Sun) and divide by 225. Then multiply that by the (Sun's) own (tabulated) epicycle and divide by 80: the result thus obtained subtracted from or added to the (Sun's) mean daily motion (according as the Sun is in the half-orbit beginning with the anomalistic sign Capricorn or in that begining with the anomalistic sign Cancer) gives the true daily motion (of the Sun).

A rule for finding the true daily motion (called *jivabhukli*) of the Moon:

15-17. (When the Moon is in the odd quadrant) subtract the part of the bahu due to her mean anomaly lying in the elementary are corresponding to the current Rsine-difference (antyajivadhanus-khanda) from the daily motion of the (Moon's) mean anomaly; (when the Moon is) in the even quadrant, subtract the remainder obtained by subtracting that (part) from 225. Then take (as many) R sine-differences in the reverse order, (if the Moon is) in the odd quadrant, or in the serial order, if the Moon is in the even quadrant, as correspond to (the above residue of the motion of the (Moon's) mean anomaly (literally, the mean daily motion of the moon diminished by that of its apogee).

(To the sum of those Rsine -differences) add the first and last elementary areas which are to be determined by proportion with the Rsine-differences (corresponding to those elementary ares). Then calculate the (Moon's) equation of the centre (phala) corresponding to that (i.e. multiply that by Moon's tabulated epicycle and divide by 80). The (Moon's) mean daily motion, when diminished or increased by that equation (according as the Moon is in the half-orbit beginning with the anomalistic sign Capricorn or in that beginning with the anomalistic sign Cancer), becomes truer than the true.

Another rule for finding the motion of the Sun or Moon for the day elapsed or for the day to elapse:

18. The difference between the longitudes (of the Sun or Moon) computed for (sunrise) today and for (sunrise) yesterday is the motion (of the Sun or Moon) which has taken place (on the day elapsed). The difference between the longitudes (of the Sun or Moon) computed for (sunrise) tomorrow and for (sunrise) today is stated to be the motion (of the Sun or Moon) which will take place (today)

A rule for determining the true distance in minutes of the Sun or Moon on the basis of the eccentric (*pratimandala*) theory:

19-20. Subtract ( the Rsine of) the greatest equation of the centre from or add that to (the R sine of ) the *koti* (due to mean anomaly) depending on the anomalistic quadrant (i.e., according as the Sun or Moon is in the second and third or first and fourth anomalistic quadrants). The square root of the sum of the squares of that and (the R sine of) the *bahu* (due to mean anomaly) is the hypotenuse. By that hypotenuse multiply (the Rsine of) the greatest equation of the centre, and then divide (the product) by the radius: add this result to or subtract that from the previous (R sine of the) *koti* (as before) Continue this process until two successive approximations for the hypotenuse are the same (up to minutes). (Thus is obtained the true distance of the Sun or Moon).

A rule for the determination of the Sun's true longitude (for mean sunrise at the *svaniraksa* place) under the eccentric theory:)

21-23. Multiply the radius by the Rsine of the *bhuja* (due to the Sun's mean anomaly) and divide (the product) by the (Sun's true) distance. Add the arc correspodning to that (result) to the longitude of the (Sun's) own apogee depending on the anomalistic quadrdant (occupied by theSun) (as follows):

(When the Sun is in the first anomalistic quadrant, add) that arc itself, (when the Sun is in the second anomalistc quadrant, add) half a circle (i.e. 180□) as diminished by that are (when the Sun is in the third anomalistic

quadrant, add) half a circle as increased by that are, and (when the Sun in the fourth anomalistic quadrant, add) a circle as diminished by that are, (when the Sun is in the third anomalistic quadrant, add) half a circle as increased by that arc, and (When the Sun is in the fourth anomalistic quadrant, add) a circle as diminished by that arc: the result is that true longitude of the Sun (for mean sunrise at the place where the local meridian intersects the equator).

This is stated to be the determination (of the Sun's true longitude) under the eccentric theory. The greatest equation.

A rule of finding the Sun's bhujantara correction under the eccentric theory.

24. The (mean) daily motion (of the Sun) multiplied by the difference between the (Sun's) true and mean longitudes computed for the local place and (the product then) divided by the number of minutes in a circle (i.e. by 21600) gives, as before, the (Sun's) *bhjantra*.

The bhujantara correction is, as stated before, the correction for the equation of time due to the eccentricity of the ecliptic.

An approximate formula for finding the Rsine of the Sun's declination:

25. The Rsine of the Sun's longitude corrected for the three corrections (viz. desantra, bahuphala, and bhujantara), as multiplied by 13 and divided by 32, is ( the Rsine of) the Sun's declination. The remaining determinations (such as the calculation of the day-radius, etc.) should be made as before.

A rule relating to the determination and application of the correction due to the ascensional difference of the Sun (called *cara-samskara* or *cara* correction):

26-27. The (mean daily motion (of the Sun) multiplied by the asus of the (Sun's) ascensional difference and divided by the number of asus in a day and night (i.e., by 21600) should be subtracted from or added to the (Sun's) longitude computed for sunrise or sunset respectively. Provided that the Sun is in the northern hemishere; if the Sun is in the southern hemisphere, it should be applied reversely.

In the case of other planets, this correction is determined by proportion (with the Sun's ascensional difference and the planet's mean daily motion); the law for its addition or subtraction (to the planet's true longitude) is the same as in the case of the Sun.

A rule for finding the semi-durations of the day and night:

28. (When the Sun is ) in the northern hemisphere, one fourth of the total duration of the day and night increased by the (Sun's ascensional difference, and (when the Sun is) in the southern hemisphere, one-fourth of the total duration of the day and night diminished by the (Sun's ascensional difference is the measure of half the day. The measure of half the night is obtained contrarily.

This can be easily seen to be true from the celestial sphere.

Rules relating to the corrections for the Moon:

29-30. Multiply the (Moon's) mean daily motion by the Sun's equation of the centre and then divide (the product) by the number of minutes in a circle (i.e., by 21600): (the result is the bhujantra correction for the Moon). Add it to or subtract it from the Moon's (mean)longitude (corrected for the longitude of the local place) in the same way as in the case of the Sun.

All remaining corrections for the Moon are prescribed as in the case of the Sun.(The bhujantara correction) for the remaining planets also is calculated from the Sum's equation of the centre.

The general formula for the bhujantra correction is :

bhujantra correction

$$\frac{\text{(Sun's equation of the centre) x (planet's mean daily motion)}}{21600}$$

The formula for the bhujantra correction for the Moon, stated in the text, is a particular case of this.

We have seen above that in the case of the Sun four corrections are applied in the following order.

(1) the longitude correction. (2) the bhujaphala correction (i.e.equation of the centre), (3) the bhujantra correction (i.e. the correction due to the Sun's equation of the centre). (4) the corection due to the Sun's ascensional difference.

In the case of the Moon, the same four corrections are applied in the following order: (1) the longitude corection. (2) the bhujantara correction (i.e., the correction due to the Sun's equation of the centre) (3) the bhujaphala correction (i.e., the Moon's equation of the centre). (4) the correction due to the Sun's ascensional difference.

Calculation of the tithi :

31-32. Divide the true longitude of the Moon as diminished by that of the Sun by 720 minutes (of arc); the quotient (obtained) denotes the number of tithis (elapsed). Miltiply the remainder by 60 and divide (the product) by the difference between the (true) daily motions of the Sun and the Moon; then are obtained the ghatis, vighatis, and asus (elapsed of the current tithi). (The time

is ghatis, vighatis,etc. of) the current tithi to elapse or elapsed is measured from sunrise.

A lunar (or synodic) month is defind in Hindu astronomy from one new moon to the next. There are thirty *tithis (*lunar days) in a lunar month . The first *tithi* begins at new moon (when the Sun and the Moon have the same longitude ) and continues till the Moon, due to her rapid motion, is 12□ (or 720) in advance of the Sun ; the second *tithi* then begins and continues till the Moon is 24□ in advance of the Sun : third *tithi* then begins and continues till the Moon is 36□ in advance of the Sun; and so on.

A lunar month is divided also into two halves, the light half and the dark half begins at new moon and continues till full moon, and the dark half begins at full moon and continues till new moon.Evidently there are fifteen *tithis* in each half. The *tithis* falling in the two halves are numbered 1, 2, 3,...........

**Calculation of the karana**

33. The karanas (elapsed) are obtained by taking "half the measure of a *tithi* (i.e., 360 minutes )" for the diviser , and are counted with Bava. But the number of karanas elapsed in the light half of the month should be diminished by one, whereas those elapsed in the dark half of the month should be increased by one. This is what has been stated.

**Calculation of the naksatra :**

34. The true longitude of a planet reduced to minutes and then divided by 800 gives the number of naksatras passed over (by the planet). From the remainder (multiplied by 60 and) divided by the (planet's true daily) motion are obtained the ghatis elapsed (since the planet's entrance into the current naksatra).

**The phenomenon of vyatipata :**

35-36 When the sum of the (true) longitudes of the sun and the Moon amounts to half a circle (i.e., $180^0$), the phenomenon is called (lata) vyatipata; when that (sum) amounts to a circle (i.e., $360^0$), the phenomenon is called vaidhrta (vyatipata) ; and when that (sum) extends to the naksatra Anuradha (i.e., when that sum amounts to 7 signs, 16 degrees, and 40 minutes), the phenomenon is called sarpamastaka (vyatipata).

The (lata) vyatipata occurs when the Sun and Moon are in different courses of motion (ayana) and their (true) declinations are equal. Its region is half a circle, but due to the Moon's latitude it may be more or less.

**Calculations relating to the planets, Mars, etc.:**

37. (In the case of the planets, Mars, etc.) the determination of the direct and inverse Rsines (relating to the kendra, i.e., mandakendra and sighrakendra) as also the calculation of the bhuja and koti etc. is to be made as in the case of the Sun. The differences (in the case of Mars, etc.) will now be stated.

**A rule for finding the (planet's) corrected epicycle :**

38-39 (i) Multiply Rsine or Reversed-sine (of the part of the kendra lying in the current quadrant), according as the (current) quadrant is odd or even, by the difference between the (planet's) own epicycles. (for the beginnings of the odd and even quadrants) and then divide ( the product) by the radius; and apply the result (thus obtained) to the (planet's) epicycle (for the beginning of the current quadrant). Subtract (that result), when the epicycle (for the beginning of) the current quadrant is greater; add (that result), when the epicycle for (the beginning of) the current quadrant is smaller. Thus is obtained the (planet's) corrected epicycle.

Rule for finding the kendraphala (i.e., mandakendra-phala or sighrakendra-phala) :

39(ii). By that (corrected epicycle) multiply the Rsine of the kendra of the desired planet and then divide (the product obtained) by 80 ; this is known as the (kendra) phala.

Procedure to be adopted for finding the true geocentric longitude in the case of Mars, Jupiter, Saturn, Mercury and Venus:

40-44. Calculate half the arc corresponding to the (planet's) mandakendraphala and apply that to the (planet's) mean longitude depending on the quadrant (of the planet's kendra) as in the case of the Sun.

(Then calculate the sighrakendraphala). Multiply the radius by the sighrakendraphala and divide (the product) by the (planet's) sighrakarna ; then reduce that arc. Apply half of that arc to the longitude obtained above, reversely (i.e., add when the sighrakendra is in the half orbit beginning with the sign Aries and subtract when the sighrakendra is in the half orbit beginning with Libra).

Therefrom calculate (the arc corresponding to) the manda(kendra)phala and apply the whole of that to the mean longitude of the planet. Thus are obtained the true-mean longitudes of Mars, Saturn, and Jupiter.

The true-mean longitude corrected for the arc derived from the sighrakendraphala (literally, the arc corresponding to the result derived from the longitude of the sighrocca minus the true-mean longitude of the planet) is

known as the true longitude . The method (to be used) for the remaining planets (i.e., Mercury and Venus) is now being told.

The longitude of the (planet's) mandocca (i.e., apogee) reversely increased or decreased by half the arc derived from the sighrakendraphala determines the true-mean longitude (of the planet). And that (true-mean longitude) corrected for the arc derived from the sighra (kendraphala) is known as the true longitude.

A rule relating to the eccentric theory :

45-46. The wise (astronomer) should apply the eccentric theory here (i.e., in the case of the planet's Mars, etc) also. (Under this theory the mandocca and sighrocca operations are as follows :)

To the longitude of the mandocca ("apogee"), apply (the spasta-bhuja due to the mandakendra, as a positive correction) in the manner prescribed above (in stanza 22) From the longitude of the sighrocca subtract the spasta-bhuja (due to the sighra-kendra) (as follows) :

(When the sighrakendra is) in the first and second quadrants, subtract from the longitude of the sighrocca the spastabhuja itself and that subtracted from half a circle (i.e., $180^0$) respectively ; (when the sighrakendra is) in the remaining quadrants (i.e., third and fourth), subtract that (spasta-bhuja) as increased by half a circle and that (spasta-bhuja) subtracted from a circle respectively.

A rule for finding the mandakarna and sighrakarna :

47. Multiply the radius by the (planet's) corrected epicycle and then divide (the product) by 80; then subtract the quotient from or add that to the Rsine of the corresponding koti (due to the kendra) in accordance with the quadrant (of the kendra): and then calculate the (planet's) karana as before.

Procedure to be adopted for finding the true longitude of the planets under the eccentric theory :

48-54. Add half the difference between the (mean) planet corrected by the mandocca operation and the mean planet to or subtract that from the mean planet according as the (mean) planet as corrected for the mandocca operation is greater or less(than the mean planet). (The planet thus obtained is called the once-corrected planet). Then correct it by the sighrocca operation. (The planet thus obtained is called the twice-corrected planet). Then find the difference between the two planets thus obtained (i.e., the once-corrected and twice-corrected planets); divide that by two: and apply it to the once-corrected planet, as before. Whatever is thus obtained should be again corrected by the *mandocca* operation. Next calculated the difference between the twice-corrected planet as corrected by the *mandocca* operation, and that (twice-corrected planet). Apply whatever be the difference between the twice-corrected planet as corrected by the *mandocca* operation and the twice-corrected planet to the

mean longitude of the planet, as before. That (i.e.,the resulting longitude) corrected by the *sighrocca* operation is the true longitude of the planet.

Thus has been stated the method for finding (the true longitudes of) Mars, Saturn,and Jupiter under the eccentric theory. Now is described the procedure to be adopted in the case of the remaining planets (viz.mercury and Venus).

(First of all obtain the mean planet as corrected by the *sighrocca* operation). Then add half the difference between the mean planet corrected by the *sighrocca* operation and the mean planet to or subtract that from the planet's *mandocca,* according as the mean planet corrected by the *sighrocca* operation is less or grater (than the mean planet). Thus is obtained the true *mandocca.* Then find out,by the method under the eccentric theory, the correction due to the true *mandocca* for Mercury as well as for Venus.The mean longitudes of Mercury and Venus each corrected for that and thereafter for the correction due to the *sighrocca* are known as true longitudes of the planets.

The procedure for finding the true longitudes of the superior and inferior planets stated in stanzas 40-44 according to the epicyclic theory has been translated in the above stanzas into the ecccentric theory. The results in both cases are the same.

The mothod is to find the difference between (1) the mean planet corrected by the *mandocca* operation and (2) the mean planet

Further instructions relating to mandakarna and sighrakarna:

55. When the Rsine of the greatest correction (antyaphala) is to be subtracted from the Rsine of the koti (due to the kendra), but subtraction is not possible, then subtract reversely (i.e., the latter from the former). Determine the mandakarna by the method of successive approximations (as in the case of the Sun or Moon) and the sighrakarna by a single application of the process (as taught in stanza 47).

A rule pertaining to the direct and retrograde motions of a planet :

56-57. Having applied to the longitude of the sighrocca half the difference between the true and mean longitudes (of a planet) positively or negatively, depending upon (whether) the mean longitude (of the planet is greater or less than the true longitude ) , determine whether the motion of the planet is vakra or ativakra or whether it is the end of the vakra motion.

The true longitude of the planet having been subtracted from the longitude of the (corrected) sighrocca, when the difference is 4 signs, the planet is about to take up vakra (retrograde) motion; when 6 signs, it is in ativakra (maximum retrograde) motion; and when 8 signs, it soon abandons the regressive path.

The difference between the true longitudes of a planet computed for (sunrise on ) the day to elapse (i.e., today) and for (sunrise on) the day elapsed (i.e., yesterday) is the (true) daily motion (of the planet for the day elapsed).

Hindu astronomers have recognised eight kinds of motion of the planets. According to the Surya-siddhantha, these are : (1) vakra (beginning of regression), (2) ativakra (maximum regression), (3) kutila (end of regression and beginning of direct motion), (4) manda (slow), (5) mandatara (slower), (6) sama (mean), (7) sighra (fast), and (8) sighratara (faster). Of these, says the author of the Surya-siddhanta, the first three are the different kinds of retrograde motion and the last five the various forms of direct motion. The above stanzas 56 and 57 deal with the three varieties of retrograde motion. The details of the five varieties of direct motion are given by Sripati in his Siddhanta-sekhara. According to him, the motion is said to be “very fast”, when the planet (measured from its sighrocca) is in the beginning of the sign Aries or Pisces; “fast”, when in the beginning of Taurus or Aquarius; “mean” when in the beginning of Gemini or Capricorn; “slow”, when in the first half of Cancer or in the last half of Sagittarius ; and “very slow”, when in the first half of Sagittarius or in the last half of Cancer.

A rule for finding the true daily motion (called jivabhukti) of the planets :

58-63. Multiply the (planet’s) own (mean) daily motion by the current Rsine-difference relating to the mandocca (i.e., the current Rsine-difference corresponding to the mandakendra of the planet) and again by the number of minutes in a sign as multiplied by 10 (i.e., by 18000). Add half of that to or subtract that from the (planet’s) mean daily motion according to ( the law of addition and subtraction in) the (four) quadrants.2 (Thus is obtained the once-corrected daily motion).

Subtract that from the daily motion of the sighrocca. Multiply whatever is obtained (i.e., sighrakendrajya gatiphala) by proceeding with the remainder in accordance with the rule “kendrantyajiva etc”. (stated in the previous stanza ) by the radius and divide by the sighrakarna (of the planet) ; (and reduce the resulting Rsine to the corresponding arc) Add half of that (arc) to or subtract that from (the once-corrected daily motion) in accordance with the law (of addition and subtraction ) for the correction due to sighrocca. (Thus is obtained the twice-corrected daily motion).

Then add the entire of the mandakendrajya gatiphala (derived from the current Rsine-difference corresponding to the mandakendra of the twice-corrected Planet) to or subtract that from the (planet’s) mean daily motion (according to the law of addition and subtraction in the four quadrants). Set down the result at two places. At one place (subtract that from the daily motion of the sighrocca and then ) calculate (the arc corresponding to) the sighrakendrajya gatiphala. Add the entire of that (arc) to or subtract that from the result kept at the other place (according to the law of addition and

subtraction in the four quadrants). Thus is obtained the desired true daily motion (of the planet).

When the result derived from the sighra operation (i.e., the arc corresponding to the sighrakendrajyagatiphala) cannot be subtracted from that, the difference between the two then denotes the value of the true daily motion and the planet is said by the learned to be retrograde.

This is the method for finding the true daily motion in the case of Jupiter, Saturn, and Mars. Now is being described the method for Venus and Mercury.

Increase or diminish (as usual) the mean daily motion of Venus or Mercury by the entire motion-correction (i.e., mandakendrajyagatiphala) determined from the corrected mandakendra and also by that obtained by proceeding according to the rule "sighrantyajiva etc". This (sum or difference) is the true daily motion (of Venus or Mercury). Thus has been stated the difference of procedure (in the case of the superior and inferior planets).

The daily motion thus obtained is always very nearly equal to the true daily motion and should be made use of in practical calculations.

A rule for finding the longitudes of the Sun and the Moon at the end of the parva-tithi :

64. Multiply the unelapsed part of the (next) tithi by the (true) daily motions of the Sun and the Moon and divide (each product) by the difference between the (true) daily motions (of the Sun and Moon). The longitudes of the Sun and the Moon increased or diminished (in the two cases respectively) by the quotients (thus obtained) should be known as the longitudes agreeing to minutes of the Sun and Moon - the causes of the performances of the world.

## CHAPTER V

## ECLIPSE OF THE SUN

1. Now shall be given the solar eclipse as taught by Acharya Aryabhata. At the beginning of that one should know the determination of the elements (to be used).

Mean distances in yojanas of the Sun and Moon :

2. (The mean distance ) of the Sun is 459585 (yojanas); that of the Moon is 34377 (yojanas).

A rule for converting true distances known in minutes into true distances in yojanas :

3. These (severally) multiplied by their true distances in minutes (as determined before) and divided by the radius (i.e., 3438 minutes) are known as the true distances in yojanas of the Sun and the Moon.

Diameters of the Earth, the Sun, and the Moon in terms of yojanas :

4. The diameter, in terms of yojanas, of the Earth has been stated by the learned to be 1050; of the Sun 4410; and of the Moon,315.`

The following table gives the diameters and distance of the sun and the moon and their ratio according to Bhaskara II, and also according to modern astronomers.

**Coparatice table of diameters and distances of the sun and moon.**

| | Bhaskara I | Sripati | Bhaskara II | Modern,in miles |
|---|---|---|---|---|
| Sun's diameter in *yojanas* | 44106522 | 6522 | 86400 | |
| Sun's distance in *yojanas* | 45958568487068937792900000 | | | |
| Ratio | 009596009596 | 009523 | 009461 | 0093 |
| Moon's diameter in *yojanas* | 315 | 480 | 480 | 2160 |
| Moon's distance in *yojanas* | 343775156651566238900 | | | |
| Ratio | 009163009163 | 009308 | 009308 | 009 |

This table shows that, although the values of the diameters and mean distance of the Sun and the Moon given by the different authorities the differ, their ratio are practically the same. It may be pointed out that it is these ratio and not the diameters or distance that are used in the calculation of the eclipses-a fact which is partly responsible for the great accuracy attained by Hindu astromers in the prediction of the eclipses.

A rule for finding the angular diameters of the sun and the Moon:

5. The diameters of the Sun and tha Moon when (severally) multiplied by the radius and devided by their true distance in yojans become the (angular) diameters in minutes.i

Formulae for the true (i.e., angular) diameters of the sun, the Moon, and the shadow in terms of the true daily motions of the Sun and the Moon:

6-7. Five-ninths of the (minutes of the Moon's true) daily motion and one -twenty-fifth of the (minutes of the Moon's true) daily motion /9 treated as minutes) respectively increased and diminished by the seconds equal to one-fourths of themselves are to be known as the true diameters of the Sun and

Moon (respectively). One-tenth of (the minutes of) the moon's true daily motion (treated as minutes) plus one-sixteenth of the same treated as second is stated to be the (true) diameter of the shadow.

A rule for the determination of the (sayana) longitude of the meridian-ecliptic point for the time of geocentric conjunction of the Sun and Moon:

8-11. Now is stated the method for (finding the longitude of) the meridian-ecliptic point. Those proficient in the(astronomical) science should know that the determination (of that) is made with the asus due to right ascension (i.e., with the times in asus of rising of the signs at the equator).

From the asus intervening between midday and the tithyantha ("the time of geocentric conjunction of the sun and Moon") one should substract in the forenoon the asus corresponding to the degrees tracersed of the sign occupied by the Sun (at the tithyanta) and in the afternoon the asus curresponding to the degree to the traversed. The degrees (traversed or to be traversed) should be (respectively) substracted from or added to the longitude of the sun ( for tithyanta). The complete signs determined with the help of the asus of the right ascensions of the signs and whatever (fraction of a sign) is obtained by proportion should also be (respectively) substracted or added by those who know the true principles of the science of time.This (i.e., the longitude thus obtained) is the true (sayana) longitude of the meridian-ecliptic point. So had come out of the mouth of the illustrious (Acarya arya)bhata.

The five Rsines relating to the Sun and Moon:

12. The orbitsof the Sun and tha Moon being different, the (five) Rsines for them are said to differ. This (difference)is indicated by the words "svadrkksepa etc." of the master (aryabhata I).

The five R sines contemplated here are the so called udayajya, madhyajya, drkksepajya, drggya and drggatijya, . Rules for finding these are given in the next eleven stanzas.

A rule for finding the Sun's udayaja:

13, Multiply the Rsine of the bahu due to the (sayana) longitude of the rising point of the ecliptic by (the R sine of) the Sun's) greatest declination and then divide ( the product) by (the Rsine of) the colatitude: the quotient is the Sun's true udayajya.

A rule for finding the Moon's udayajya :

14-16 (i) The Rsine of (the longitude of) the rising point of the ecliptic minus (the longitude of ) the Moon's ascending node, multiplied by 15 and divided by

191, is the Rsine of the (Moon's) latitude corresponding to the rising point of the ecliptic. When the declination and (Moon's) latitude corresponding to the rising point of the ecliptic are of like direction, take their sum ; in the contrary case, take their difference. The radius multiplied by the Rsine of the resulting arc (of the sum or difference) and then divided by (the Rsine of ) the colatitude gives the Moon's udayajya.

The Moon's udayajya is the Rsine of that part of the local horizon which lies between the east point and the rising point of the Moon's orbit.

Rules for finding the madhyajyas of the Sun and the Moon :

16(ii)-18. Calculate the Rsine of the celestial latitude (of the Moon) from the longitude of the merridian-ecliptic point minus the longitude of the Moon's ascending node.

When the declination of the meridian-ecliptic point and the local latitude are of like direction, take their sum; in the contrary case take their difference; (and determine the Rsine of that sum or difference). This is the Sun's madhyajya which has the same direction as the above sum or difference.

In the case of the Moon, take the sum or difference of the local latitude, the declination (of the meridian-ecliptic point), and the (Moon's) latitude (corresponding to the meridian-ecliptic point) on the basis of likeness or unlikeness of direction; and then determine the Rsine of the resulting arc. This is the (Moon's) madhyajya, which has the same direction as the resulting arc.

The Sun's madhyajya is the Rsine of the zenith distance of the meridian-ecliptic point. The Moon's madhyajya is the Rsine of the zenith distance of the meridian point of the Moon's orbit.

A rule for the determination of the drkksepajyas of the Sun and the Moon:

19. Take the product of (the Sun's or Moon's) own madhyajya and udayajya, then divide (the product) by the radius and then take square (of the quotient). Subtract that from the square of the (own) madhyajya : the square root of that (difference) is known as (the Sun's or Moon's) drkksepajya.

20-22. Calculate the Rsine of the Sun's zenith distance (drgjya) from the nadis elapsed (since sunrise in the forenoon) or to elapse (before sunset in the afternoon) in accordance with the method stated before. The method for (finding the Rsine of the zenith distance of) the Moon is now being described.

Take the sum or difference of the celestial latitude and declination of the Moon for the time of geocentric conjunction (of the Sun and Moon) according add they are of like or unlike direction. The Rsine of the resulting sum or

difference is (the Rsine of) Moon's (true) declination. From that calculate the day-radius, the earthsine, and the asus of the ascensional difference. With the help of these and the nadis elapsed (since sunrise in the forenoon) or to elapse (before sunset in the afternoon) obtain the Rsine of the zenith distance. (This is the Rsine of the Moon's zenith distance).

A rule for finding the drggatijyas of the Sun and the Moon :

23. Obtain the difference between the squares of the (Sun's as also of the Moon's) own drgjya and drkksepajya, and then take their square-roots. These (square-roots) are the drggatijyas of the Sun and the Moon.1

The Sun's drggatijya is the distance of the zenith from the plane of the secondary to the ecliptic passing through the Sun. The Moon's drggatijya is the distance of the zenith from the plane of the secondary to the Moon's orbit passing through the Moon.

In later astronomical literature , the drggatijya is used to mean the Rsine of the altitude of the central ecliptic point ( i.e., the point of the ecliptic nearest from the zenith); and the distance of the zenith from the plane of the secondary to the ecliptic is denoted by the term drggatijya.

A rule for finding the time of apparent conjunction of the Sun and Moon :

24-27. Severally multiply the own drggatijyas (of the Sun and the Moon) by the Earth's semi-diameter and divide the products by the respective true distances in yojanas. The quotients (thus obtained) are known as the lambanas (of the Sun and the Moon) in terms of minutes (of arc), etc.

Multiply their difference by 60 and divide that by the difference between the true daily motions of the Sun and the Moon. Thus are obtained the ghatis etc. (of the lambana). In the forenoon, subtract them from, and in the afternoon, add them to the time of geocentric conjunction of the Sun and Moon. (Then is obtained the first approximation to the time of apparent conjunction).

The lambana computed for the middle of the day is subtracted from the time of geocentric conjunction when the Moon's udayalambana is north and added when south.

Repeat this process until the nearest approximation (to the lambana for the time of apparent conjunction) is arrived at the corresponding displacements should be given by the learned to (the longitudes of) the Sun and the Moon,as in the case of the tithi (i.e., the time of conjunction of the sun and the moon).

The term lambana is the technical term for "parallax in longitude." When used alone in connection with asolar eclispse it generally stand for the difference between the parallaxes in longitude of the sun and the moon

A rule for finding the true nati:

28-32. Multiply the drkksepajyas (of the sun and the moon),obtained by the method of successive approximations,(severally) by the Earth's semi-diameter,and divide (the resulting products) by the true distance in yojanas (of the sun and the moon respectively): the quotients are in minutes of are ( the parallaxes in latitude of the sun and the moon). Take their difference, provided that the madhyajyas of the sun and the moon are of llike direction of the nati) take the direction of the moon's (madhyajya).

Multiply the Rsine of the longitude of the Moon minus the longitude of the Moon's ascending node by 270, and then divide that product by the Moon's true distance in minutes. Thus is obtained the true celestial latitude of the Moon. This increased by that (nati) (provided the two are of like direction) is the true nati. In case they are of unlike directions,take their difference.The difference is then called the (true) nati.

Thus is obtained the true avanati (or true nati) for the middle of the eclipse as determined form the drkksepa and the true latitude of the sun and moon for the time of apparent conjunction (literally, the time of geocentric conjunction corrected for the lambana-difference).

On the possibility of a solar eclipse:

33. An eclipse of the Sun will not occur if the (true) nati is equal to (or greater than) half the sum of the diameters of the Sun and the Moon. It is possible when it (i.e., the true nati)is less (than that).

A rule for the determination of the sparsa-sthityardha or moksasthityardha:

34-39. Multiply the square root of the difference between the squares of half the sum of the diameters of the Sun and Moon and of the (true) nati by 60 and then divide (the product) by the motion-difference (of the Sun and the Moon) : thus are obtained the ghatis of the sthithyardha. By these ghatis diminish and increase the time of apparent conjunction as obtained by the method of successive approximations. Then are obtained the (approximate) times for the first and last contacts respectively. Proceeding with them, calculate the (ten) Rsines (for the Sun and the Moon), etc., (and obtain the nearest approximations to the lambanas for the times of the first and last contacts). Always add, in the case of a solar eclipse, the nadis of the difference between the lambanas for the first contact and the apparent conjunction to the sthityardha : (the result is the sparsa-sthityardha) Also add the (nadis of the difference between the) lambanas for the apparent conjunction and the end of the eclipse to the sthityardha : the result is the moksa-sthityardha. The sthityardhas thus obtained are very accurate : I say this raising my hands aloft (i.e., with firm determination).

When the first contact and apparent conjunction occur in different halves (eastern and western) of the celestial sphere, then the entire lambana (in nadis)

for the time of the last contact is always added to the sthityardha. The same procedure is also adopted when the apparent conjunction occurs at noon.

The term sthityardha means "half the duration (of an eclipse)", The sparsa-sthityardha is an interval of time between the first contact and the apparent conjunction. The moksa-sthityardha is the time-interval between the apparent conjunction and the last contact.

A rule for the determination of the vimardardha:

40. The nadis of the vimardardha are to be detemined from the square root of the difference between the squares of (i) the difference between the semi-diameters of the eclipsed and eclipsing bodies and (ii) the Moon's latitude corrected for the nati)

The term vimardarha means :half the duration of the totality of an eclipse:,i.e.,the time-interval between the immersion and the apparent conjunction or between the apparent conjunction and the emersion. The time-interval between the emersion and the apparent conjunction is called the sparsa-vimardardha and that between the apparent conjunction and the emersion is called the moska-vimardardha.

The above stanza gives the method for finding the first approximation to the vimardardha in minutes of arc. The corresponding nadis are obtained by multiplying that by 60 and dividing by the difference between the true daily motions of the sun and moon. The nearest approximation to the sparsa-vimardardhas are obtained as in the case of the sthityardhas.

A rule for knowing the time of actual visibility of the first contact in the case of a solar eclipse:

41. On account of the brightness of the Sun, the time of (actual visibility of) the first contact(in tha case of a solar eclipse) is the (computed) time of the dirst contact plus the time corresponding to the minutes of arc amounting to one-eight of the Sun's diameter.

Aryabhata I says:"When the moon eclipses the Sun,even though one-eight part of the Sun is eclipsed this is not perceptible because of the brightness of the Sun and the transparency of the Moon's circumference."

A rule for finding the magnitude and direction of the aksavalana:

42-44. Multiply the Rversed-sine of the asus intervening between midday and the tithi (i.e., the time of the first contact, the middle of the eclipse, or of the last contact) by the Rsine of)the (local) latitude and devide that (product)by the radius. Reduce the resulting Rsine to the corresponding arc (called aksa-valana) and determine its direction.

When the above asus exceed (those corresponding to)a quadrant, add the Rsine of the excess to the radius and operate as before ;and then find the direction.

The direction (of the aksa-valana) in the eastern and western halves of the disc (of the eclipsed body)are north and south respectively. To the west of the sky (i.e.,in the afternoon). the aksa-valana is always of the contrary direction.

A rule for the determination of the magnitude and direction of the ayana-valana:

45. The (Sun's) declination determined from the Rversed sine of the longitude of the Sun or Moon as increased by three signs (treated as the Rsine of the bhuja) (is the ayana-valana). Its direction in the eastern half (of the disc of the eclipsed body) is the same as that of the ayana (of the Sun or Moon).

A rule for finding the value of the resultant valana (spasta-valana) for the circle drawn with half the sum of the diameters of the eclipsed and eclipsing bodies as radius:

46-47. When they (i.e., the aksa-valana and the ayana-valana) are of unlike directions,take the differnce of their arcs; in the country case, take their sum. Multiply the Rsine of that (sum of difference) by half the sum of the diameters of the eclipsed and eclipsing bodies and divide(the product) by the radius.Add whatever is thus obtained to the(moon's true) nati, provided that they are of like directions; in the contrary case, take their difference: the resulting sum or difference is the valana.

The next twenty stanzas relate to the projection (i.e.,graphical representation) of an eclipse.

A method for ascertaining the centre of the eclipsing body for the times of the first and last contacts(called the sparsa-bindu and the moksa-bindu respectively):

48-53. By means of a pair of compasses, whose smooth and large body is graduated with angulas and subdivisions there of and which is embellished by the pointed end of a smoothened chalk-stick placed into its mouth, construct on the ground a circle with half the measure ,in angulas,of the eclipsed body as radius, and another (concentric circle) with half the sum of the diameters of the eclipsed and eclipsing the bodies as radius. (Through the common centre) then draw the east-west line and, with the help of a fish-figure, the north-south line. From the centre then lay of the valana ( for the first or last contact) towards the north or south (according to its direction) ; draw a fish-figure there ; and (through its head and tail) carefully draw a line to meet the outer circle.

At the meeting point of the outer circle and that line set a point. (This is the centre of the eclipsing body for the time of the first or last contact). From that point stretch out a line to rteach the centrte. Where this line is seen to intersect the circumference of the eclipsed body,lies the point of contact or seperation of the Sun's disc.

One minute of arc should be taken as equivalent to one half of an angula or as it appears in the sky.

A method for determining the centre of the eclipsing body for the middle of the (solar) eclipse (called the madhyabindu)

54-57. The valana for the middle of the eclipse is taken without the addition or subtraction of the nati. When that and the nati are of like direction, the (madhya)valana should be laid off towards the east; when they are of unlike directions, it is stretched out from the centre towards the west. With the help of a fish-figure (drawn about the point thus obtained), a line should then be drawn in the direction of the nati. From the meeting point of that with the outer circle, the intelligent should then draw a line to reach the centre (of the circle). The nati should then be laid off from the centre along that line. At the end of that lies the centre of the eclipsing body at the middle of the eclipse (i.e., the madhya-bindu). The two points (already marked) are the centre of the eclipsing body for the times of the first and last contacts (i.e., the sparsa-bindu and (moksa-bindu).

When the nati (for the middle of the eclipse) is of south direction, it should be laid off towards the south; when it is of north direction,it is laid off towards the north.

Points of difference of procedure in the case of a lunar eclipse:

58. This (i.e., the previous rule) is the method for the middle fo the eclipse in the case of a solar eclipse. In the case of a lunar eclipse, the points of the first contact should be clearly indicated reversely.

That is, in the case of a lunar eclipse ,the following procedure should be adopted: To begin with, the madhya-valana should be laid off towards the west or east,according as the madhya-valana and the nati are of like or unlike directions. With the help of a fish-figure drawn about the point thus obtained a line should then be drawn througn that point in the direction contrary to the direction of the Moon's latitude. From the meeting point of that line with the outer circle a line should then be drawn to reach the centre of the circle. The Moon's latitude for the middle of the eclipse should then be laid off from the centre along that line.

construction of the phase of the eclipse for the time of the middle of the eclipse.

59-60. Quickly cut off the eclipsed body by means of a pair of compasses (one leg of) which is placed at the madhyabindu and (the other leg of) which is streched out by half the specified true measure of the eclipsing body.The portion thus cut off (in case the eclipse is partial), or the entire disc of the eclipsed body drawn (likhitam)in the projection (in case the eclipse is total)-all of that is clearly seen (in the sky) in that way a t the time of the middle of the eclipse.

By the word likhita,says Paramesvara, is meant total eclipse,or, in case the Moon's latitude is zero and the disc of the eclipsed body is larger, an annular eclipse.

**Construction of the path of the eclipsing body:**

61. Draw (an are of )a circle passing through the three points set down above with the help of two fish-fingures: this is the path of the eclipsing body. The phase of the eclipse of the given time is ascertained (by determining the position of the eclipsing body on that path and drawing its disc with its centre) there.

A method for calculating the phase of the eclipse for the given time:

62-63. Multiply the difference between the (true) daily motions of the Sun and the Moon by the sthityardha-ghatis minus the given time (istakala) and divide the product by sixty. Add the square of the quotient of the sqare of the Moon's nati (corrected latitude) (for the given time) and then take the square root of that (sum?). This (square root) is ( the length of)the needle joining the centres of the eclipsed and eclipsing bodies at the given time in the case of solar and lunar eclipses. (Subtract that from half the sum of the diameters of the eclipsed and eclipsing bodies). The remainder is the phase of the eclipse for the given time.

By the given time is meant the time elapsed since the first contact or the time to elapse before the last contact.

**Construction of the phase of a eclipse for the given time:**

64-65. Stretch out a fine bamboo needle (equal in lengh to that joining the centres of the eclipsed and eclipsing bodies at the given time) obliquely from the centre in such a way that its end may fall on the so called path of the eclipsing body. Taking the centre at that point,cut off the eclipsed body by means of a circle drawn with half the diamerter of the eclipsing body as radius.

As much portion is thus cut off, so much of the eclipsed body is seen to be eclipsed (in the sky).

Construction of the phase of a (solar) eclipse for the time fo immersion or emersion:

66-67. The sthityardha in terms of minutes of arc minus the minutes of the vimardardha is the means for projecting the phase of the eclipse for that time (i.e., immersion or imersion). The Sun's disc should be cut off with the help of that (i.e., that should be laid off from the sparsa or moksa bindu along the path of the eclipsing body towards the centre and the point thus obtained should be treated as the centre of the eclipsing body for that time ). The disc of the Sun should be cut off by means of a pair of compasses. The siezure (of the Sun) occurs on the western side of the disc and the separation on the eastern side.

**THE DIAMETER OF THE SHADOW**

**(2) ECLIPSE OF THE MOON**

Points of difference of procedure on the case of a lunar eclipse:

68-70. Similarly, in the case of the Moon which is the mirror for the face of the directions and exhibits (it bears ) all excellent phase and whose round body looks like the face of a damsel,too, the (ten) Rsine should be found out. The points of difference (in the procedure )are being stated.

The (five) Rsine relating to the shadow should be determined as arising from the Sun's orbit. (In place of the Sun's distance the Moon's distance is stated to be the divisor. The lambana, determined as in the case of the Sun, should be added or subtracted reversely.

Use of parallax in a lunar eclipse prescribed in the above stanzas obviously wrong. Paramesvara comments: "Thus in the case of a lunar eclipse also, the use of parallax is stated here. This say the proficients in Spherics ,is improper".

It must be mentioned that the application of parallax in the case of a lunar eclipse has not been prescribed in any other work on Hindu astronomy, on it even in the smaller work of the present author.

A rule for the determination of the diameter of the shadow, i.e., the diameter of the section of the Earth's shadow where the Moon crosses it:

71-73. Multiply the Sun's(true) distance in yogans by the Earth's diameter and divide by the difference of their diameters: thus is obtained the length of the Earth's shadow. Or, multiply the Sun's(true) distance in yojanas by 5 and divide by 16: the result is called the length of the Earth's shadaow.

From that (length of the Earth's shadow) subtract the Moon's distance. Multiply the remainder by the Earth's diameter and divide (the product) by the length of the (Earth's) shadow. Multiply the resulting quotient by the radius

and divide (the product) by the Moon's distance (in yojanas): this diameter of the shadow(in minutes of arc)

**ECLIPSES**

Views of other astronomers regarding the calculation of a lunar eclipse:

74. Others give instructions in the lunar eclipse without the use of the ten Rsine, because it causes little different in the result (and is simpler). There (i.e., in the rule stated by them) the sparsa-and moksa-stityardas arising from (the Moon's latitude for) the time of opposition of the sun and Moon (lit,middle of the eclipse) should be operated upon by the method of successive approximations.

Details of the process of successive approximations refered to above.

75-76. Multiply the (true) daily motion(of the Moon) by the time (in ghatis) of the sthityardha and divide the product by 60. Substract the quotient from or add that to the Moon's (true) longitude for the time of opposition (of the Sun and Moon), According as it is the first or last contact. From that find out the Moon's latitude; and then from (again) calculate the sthityardha. (In this way repeat the above process again and again until two sucessive approximations agree). This is the process of successive approxomations. Similar again is the process of (determining)the (sparsa-and moksa) vimardardhas.

A rule relating to the direction of the Moon's latitude to be taken in the projection of a lunar eclipse:

77. While projecting an eclipse (of the Moon), the best amongst the learned should take the direction of the Moon's latitude to be north when it is south, and south when it is Concluding stanza in praise of the method for calculating and projecting an eclipse that have been stated above:

78. This procedure regarding the Sun, the Moon, and the shadow, which has come down (to us) by tradition, has been stated here having cast off pride and jealousy. A learned person who acquires a masterly of this (procedure) shall become a (proficient) astronomer well versed all astronomical methods.

**Chapter VI**

**RISING SETTING AND CONJUNCTION OF PLANETS**

A rule relating to the visibility - correction known as asksadrkkarma :

1-2 (i). Multiply the Moon's latitude for the desired time by the Rsine of latitude of the local place, and divide (the product) by the Rsine of the

colatitude; whatever is thus obtained, say the learned, should be subtracted (from the Moon's longitude) in the case of rising of the Moon (i.e., in the eastern hemisphere) and added ( to the Moon's longitude) in the case of setting of the Moon (i.e., in the western hemisphere), provided that the Moon is to the north of the ecliptic (i.e., if the Moon's latitude is north). When the Moon is to the south of the ecliptic, the law (of addition and subtraction) is the reverse.

The correction stated in the first three stanzas of this chapter is called "the visibility - correction (drk-karma)". When we apply this correction to the true longitude of the Moon, we obtain the longitude of that point of the ecliptic which rises or sets with the apparent Moon.

The visibility-correction is generally broken up into two components : (1) the visibility-correction due to the latitude of the local place (aksa-drkkarma), and (2) the visibility-correction due to the Sun's northward or southward course (i.e. ecliptic-deviation) (ayana-drkkarma).

It follows that the formula given in the text actually gives an approximate value of the arc.

The rule stated in the text has been generally used in the cases where the latitude of the body concerned is small. In the case of fixed stars whose latitudes may be considerable, a more accurate rule is prescribed.

A rule relating to the visibility correction known as ayanadrkkarma:

2 (ii) - 3. Divide the product of the Rversed-sine of the Moon's longitude diminished by three signs, the Rsine of the Sun's greatest declination, and the Moon's latitude by the square of the radius. Whatever is thus obtained, say the learned, should be subtracted from the Moon's longitude provided that her ayana and latitude are of like direction; in the contrary case, that result should always be added to the Moon's longitude.

A rule relating to the visibility of the Moon:

4-5 (i). The Moon's longitude, which is obtained in this way after the application of the above-mentioned (visibility) corrections, is stated by the learned to be the longitude of the visible Moon (i.e., the longitude of that point of the ecliptic which rises with Moon)

When the *pranas* (of the oblique ascension) due to the degrees intervening between the Sun and the (visible) Moon, reduced to ghatis, amount to two, then the Moon is seen to rise in the clear, cloudless, starry sky after sunset.

A rule for calculating the phase of the Moon:

5(ii) - 7. (In the light half of the month) multiply (the diameter of) the Moon's disc by the Rversed-sine of the difference between the longitudes of the Moon and the Sun (when less than a quadrant) and divide (the product) by the number 6876: the result is always taken by the astronomers to be the measure of the illuminated part (of the Moon). When the difference between the Moon and Sun exceeds a quadrant, then the Moon's illuminated part of the calculated from the Rsine of that excess increased by the radius.

After full Moon (i.e. in the half of the month) the unilluminated part of the Moon is determined from the Rversed sine or Rsine of (the excess over six or nine signs respectively of ) the difference between the longitude of the Moon and the Sun is the same way as the illuminated part is determined (in the light half of the month).

A rule for the determination of the base (bahu) and upright (koti) to be used in the graphical representation of the elevation of the Moon's horns, when the calculation is made in the first quarter of the month for sunset:

9-12. (Calculation the longitudes of the Sun and the visible Moon for sunset on the day of calculation). By the help of the asus intervening between the Sun and the (visible) Moon always find out, in the manner stated before, the Rsine of the Moon's altitude. Then divide the product of the Rsine of Moon's true altitude (thus obtained) and the Rsine of the (local) latitude by the Rsine of the colatitude: thus is obtained the Moon sankvagra, which is always to the south of the Moon's rising-setting line. Then multiply (the Rsine of) the Moon's true declination by the radius and divide (the resulting product) by the Rsine of the colatitude : thus is obtained the so called Rsine of the agra of the (apparent) Moon lying to the north or south (of the ecliptic). Take their sum (i.e., the sum of the Rsines of the Moon's sankvagra and agra) when they are of like directions, and the difference when they are of unlike directions. Then reversely add or subtract the Rsine of the Sun's *agra*. Then is obtained the true value of the Moon's base (*bahu*). Then Rsine of the Moon's altitude is the upright (*koli*).

Method for the graphical representation of the elevation of the lunar horns in the first quarter of the month at sunset:

13-17. To the north or south of the Sun is (to be laid off) the (true) base (according to its direction); and to the east (of the point thus obtained) is (to be laid off) the upright; the line which joins the ends of the base and the upright is called the hypotenuse. (Taking the centre) at the meeting point of the hypotenuse and the upright, draw the Moon's disc. The hypotenuse is the east-west line of the (Moon's disc); through the middle of that (i.e. through the centre of the Moon's disc) draw the north-south line. At the extremities of the north-south line mark two points on the periphery of the Moon's disc. (Then lay

off the Moon's illuminated part) along the hypotenuse (from the west point) towards the interior of the Moon's disc and mark there the point of illumination. Thereafter always draw a circle passing through the (above-mentioned) three points. The portion lying between that (circle) and the (periphery of the) Moon's disc (lying towards the Sun) so called the illuminated part (of the Moon). The elevation, depression, or horizontalness of the Moon's horns, in whatever unit be it measured (in the figure), is clearly perceived in the sky (as in the figure).

Representation of the elevation of the lunar horns at any other time instead of sunset in the first quarter of the month:

18. This (above) method is to be followed at the sunset. At (anyother) given time, all calculations such as the determination of the Rsine of the zenith distance of the Moon for that time are prescribed to be made with the setting point of the ecliptic (taken for the Sun).

The only difference in this case is that the time to elapse before moonset, instead of being found out from the asus intervening between the Moon and the Sun (as was done in the previous case), should be found out in this case from the asus intervening between the Moon and the setting point of the ecliptic, or, as the commentator Paramesvara says, from the asus intervening between the rising point of the ecliptic and the point six signs in advance of the Moon. The asus correspond to oblique ascension as in the previous case.

Representation of the elevation of the lunar horns in the send quarter of the month:

19. When the calculation relating to the elevation of the Moon's horns is made after the eighth lunar day, the rising point of the ecliptic itself should be regarded as the Sun. And under that assumption should be made the calculation of the Rsine of the Moon's altitude, etc., with the exception of the calculation of the measure of the illuminatled part (of the Moon's disc).

A rule for the determination of the Rsine of the Moon's altitude to be used in connection with the elevation of the lunar horns:

20. The R sine of the Moon's altitude should be calculated from the asus intervening between the Sun and the Moon, or between the rising or setting point of the ecliptic and the Moon subject to the time of calculation, the asus being those obtained by applying the rule once and not successively.

A rule telling that the above calculations pertaining to the elevation of the lunar horns relate to the first half of the month only.

21. In this manner, at sunset or any other time, with the help of the longitudes of the Sun and the Moon's ascending node, should be made this calculation relating to the Moon till the fifteenth lunar day: So has been said.

A rule telling how many *nadis* before or after sunset will the Mon be seen to rise on the full Moon day:

22. Diminish the *nadis* (due to the oblique ascension of the part of the ecliptic) intervening between the Sun and the (visible) Moon (at sunset on the full moon day) (from or) by (the *nadis* of) the length of the day: so many *nadis* before or after sunset is the Moon seen (to rise on the full moon day)

A rule relating to the representation of the elevation of the lunar horns in the dark of the month:

23-25. After the end of the (light) fortnight, the Moon, lying above the horizon, is drawn by using the measure (of the R sine of the Moon's altitude) computed from (the asus due to the oblique ascension of the part of the ecliptic intervening between the visible Moon and) the rising point of the ecliptic at the given time. The upright is laid off towards the west the base is laid off along the north-south line (in its proper direction); and the hypotenuse-line is stretched out from the end of that (base) to meet the end of the upright. Then from the east point (of the Moon's figure) lay off the measure of the (Moon's illuminated part along the hypotenuse-line within the figure of the Moon; or from the west point (of the Moon's figure), lay off the (measure of the Moon's) unilluminated part.

A rule telling how to do the same at sunrise in the dark half of the month:

26. Or, perform the operation, stated above, concerning the Moon's illuminated or unilluminated part at sunrise with the aus intervening between the (visible) Moon and the Sun at that time. The time of moonrise will now be told.

A rule for getting the duration of the Moon's visibility at right in the half of the month (I quarter):

27. In the light fortnight, find out the asus due to oblique ascension (of the part of the ecliptic) intervening between the Sun and the (visible) Moon (at moonset) both increased by six, signs, by the method of successive approximations. These give the duration of visibility of the Moon (at night) (or, in other words, the time of moonset).

The process of sucessive approximations may be explained as follows: Compute the (sayana) longitudes of the visible Moon and the Sun for sunset and increase both of them by six signs. Then find out the asus ($A_2$) due to the oblique ascension of the part of the ecliptic lying between the two positions thus obtained. Then $A_1$ *asus* denote the first approximation to the duration of the Moon's visibility at night. Then calculate the displacement of the Moon and the Sun for $A_1$ *asus* and add them respectively to the longitudes by six signs;

and then find out the *asus* $(A_2)$ due to the oblique ascension of the part of the ecliptic lying between the two positions thus obtained. Then *asus* $(A_2)$ denote the second approximation to the duration of the Moon's visiblity at night. Repeat the above process successively until the successive approximations to the duration of the Moon's visibility agree to vighatis.

The time thus obtained is in terms of civil reckoning. If, however, the use of the Moon's displacement alone be made at every stage, the time obtained will be in terms of sidereal reckoning.

A rule for finding the time of moonrise in the half of the month (III quarter).

28. Thereafter (i.e., in the dark half of the month), the Moon is seen (to rise) at night (at the time) determined by the asus (due to oblique ascension) derived by the method f successive approximations from the part of the ecliptic intervening between the Sun as increased by six signs and the (visible) Moon as obtained by computation, (the Sun and the Moon both being those calculated for sunset).

Details of the method of successive approximations contemplated in the above rule :

29-31. Determine the time in asus (due to the oblique ascension of the part of the ecliptic) intervening between the rising point of the ecliptic and the (visible) Moon computed for sunset. (This is the first approximation to the required time). Now calculate the positions of the rising point of the ecliptic and the (visible) Moon for that time; and then determine the *asus* intervening between those positions again. In case the longitude of the (visible). Moon is greater than that of the rising point of the ecliptic, add these asus to the time obtained above; in the contrary case, subtract them. (This is the second approximation to the required time). Repeat this process successively unti the successive approximations to the time, the longitude of the rising point of the ecliptic, and the longitude of the rising point of the ecliptic, and the longitude of the (visible) Moon are (severally) equal (up to vighatis or minutes). At the time ascertained by this procedure for the Moon, the Moon is seen (to rise) in the night filling (the space in) all the directions with her rays.

The above rule is based on the fact that at moonrise the longitudes of the visible Moon and the rising point of the ecliptic are the same.

An alternative rule for finding the time of moonrise in the dark half of the month (III quarter)

32-33. Find out the *asus* due to the oblique ascension of the part of the ecliptic lying from the setting Sun up to the (visible) Moon; and therefrom subtract the length of the day. (This approximately gives the time of moonrise

as measured since sunset). Since the Moon is seen (to rise) at night when so much time, corrected by method of successive approximations, is elapsed, therefore the *asus* obtained above should be operated upon by the method of successive approximations.

Details of the methos of successive approximations contemplated in the above rule :

34. Find out the displacements of the Sun and the Moon for the *ghatis* (corresponding to the approximate time) obtained above and add them to the longitude of the Sun and the (visible) Moon respectively; then determine the ghatis (due to the oblique ascension of the part of the ecliptic) intervening between them; and then from those (ghatis) subtract the length of the day. (Thus is obtained the second approximation ot he the required time). Then find out the displacements of the Sun and the Moon corresponding to (the ghatis of) the remainder (and proceed as above again and again until the successive approximation agree to *vighatis*).

An analogous rule for finding the time of moonrise in the light half of the month (II quarter).

35-36. (In the light half of the month) when the measure of the day exceeds the *nadis* (due the oblique ascension of the part of the ecliptic) lying between the Sun and the (visible) Moon (computed for sunset), the moonrise is said to occur in the day when the residue of the day (i.e., time to elapse before sunset) is equal to the *ghais* of their difference. (in this case) the longitudes of the Sun and the (visible) Moon should be diminished by their displacements determined by proportion from the *nadis* (of the residue); and then should be obtained the asus (due to the oblique ascension of the part of the ecliptic) between the Sun and the (visible) Moon (thus obtained). These *asus* should be operated upon by the method of successive approximations.

Another rule for getting the time of moonrise in the dark half of the month (IV quarter):

37-38. Determine the *asus* (due to the oblique ascension of the part of the ecliptic lying) from the (visible) Moon at sunrise up to the rising Syn; then subtract the corresponding displacemtns (of the Moon and the Sun) from them (i.e., from the longitudes of the visible Moon and the Sun computed for sunrise); and on them apply the method of successive approximations (to obtain the nearest approximation to the time between the visible Moon and the Sun computed for moonrise, i.e., between the rising of the Moom and the Sun). The Moon, who is life a looking glass for the face of the directins, rises as many

*asus* before sunrise as correspond to the *nadis* obtained by the method of successive approximations.

A rule for the determination of the time of the meridian passage of the Moon, and longitudes of the Moon and the meridian ecliptic point at that time:

39. Infer by your intellect the time when the meridian ecliptic point and the Moon are together. Then, by the method of successive approximations, find out the nearest approximations for that time, the longitude of the Moon, and the longitude of the meridian-ecliptic point (for that time).

Assuming that the rising point of the ecliptic is three signs in advance of the meridian-ecliptic point, the time to elapse before or elapsed since the Moon is on the meridian is the same as the time to elapse before or elapsed since the point of the ecliptic three signs in advance of the Moon is on the horizon. Therefore in order to get an approximate time when the Moon occupies the meridian-ecliptic point one way proceed as follows: First claculate the longitudes of the Sun, the Moon, and the rising point of the ecliptic with the help of the given time. Then increase the longitude of the Moon by three signs and find the time due to the obtained is the approximate time to elapse before or elapsed since the meridian passage of the Moon. From this calculate the time of the meridian passsage of the Moon.

Details of the method of succssive approxmations contemplated in the above rule :

40. Determine the *nadis* intervening between the Moon and the meridian-eclipitc point (for the time determinedf by inference) with the help of the times of rising of the signs at Lanks. When (the longitude of the Moon is) less (than the longitude of the meridian-ecliptic point), subtract the resulting *nadis* from those corresponding to the inferred time; when greater, addition is prescribed. (For the time thus obtained calculate the longitudes of the Moon and the meridian-ecliptic point and find the *nadis* intervening between them with the help of the right ascensions of the signs as before; and then repeat the above process successively until the nearest approximation to the time of meridian passage of the Moon is obtained).

A rule for the determination of the Rsine of the Moon's meridian zenith distance:

41. By this process is obtained the Moon when she is on the meridian (lit. when her longitude is equal to that of the meridian-ecliptic point). From her celestial latitude and declination, and from the (local) latitude is determined the Rsine of her meridian zenith distance.

A rule regarding the elevation of the horns of the half-risen or half-set Moon:

42. The determination of the elevation of the horns of the healf-risen or half-set Moon is made with the help of the agra of the rising or setting point of hte Moon's orbit.

When the Moon is rising or setting, its base is obviously equal to the *agra* of the rising or setting point of the Moon's orbit. Procedure to be adopted in the case of the planets:

43. This (above-mentioned) procedure should be adopted in the case of the nector-rayed Moon; the same process is prescribed for all the planets also.

The remainder of this chapter deals exclusively with the planets.

Minimum distances of the planets from the Sun when they are visible:

44. Venus is visible when it is 9 degrees away from the Sun; Jupiter, Mercury, Saturn, and Mars are observed when they are respectively further away by two degrees in successions (i.e., when they are respectively 11°, 13°, 15°, and 17° away form the Sun).

45. Venus, which moves in its proper orbit but appears retrograde, is visible, due to profusion of its rays, when it is (only) 4½ or 4 degrees away from the Sun.

A rule telling us (1) how to convert the degrees of time into *vighatis,* and (2) how to determine the degrees of time between the Sun and a planet :

46-47. These degrees of time when multiplied by ten are called *vighatis.* (When the planet is seen) in the east, they are determined from (the oblique ascension of) the sign occupied by the Sun and the planet; (when the planet is visible) in the west, they are determined from (the oblique ascension of) the seventh sign (as measured from the sign occupies by the Sun and the planet.) (The process is as follows): Divide the oblique ascension of the sign occupied by the Sun and the planet (or of the seventh sign, as the case may be) as multiplied by the degrees of the difference between the longitudes of the planet and the Sun by 30. If the resulting time is equal to (or greater than) that stated (for that planet), the planet will be seen to rise (heliacally).

The longitude of the planet is that corrected for the visibility corrections.

Conjuction of Planets

Definition of the "divisor" to be used later:

48. The *sighra-karna* as multiplied by the *mandoccakarna* (or *manda-karna)* should be divided by the radius: the result thus obtained is called the "divisor".

A rule relating to the determination of the time and the common longitude of two planets when they are in conjunction in longitude:

49-51. If one planet is retrograde and the other direct, divide the difference of their longitudes by the sum of their daily motions; otherwise (i.e. if both of them are either retrograde or direct), divide that by the difference of their daily motions: thus is obtained the time in terms of days, etc., after

motions: thus is obtained the time in terms of days, etc., after or before which the two planets are in conjunction (in longitude). The velocity of the planets being different (in longitude). The velocity of the planets being different (literally, manifold). The velocity of the planets being different (literally, manifold) (from time to time), the time thus obtained is gross (i.e., approximate) One, proficient in astronomical science, should, therefore, apply some method to make the longitudes of the two planets agree to minutes. Such a method is possible from the teaching of the precepter or by practice (of the astronomical science).

The method to be used here is obviously the method of successive approximations.

A rule relating to the computation of the celestial latitude of a planet when it is in conjunction with another planet:

52-53. Diminish the longitude of the planet in conjunction with another planet by the degree of (the longitude of) the ascending node (of that planet); by the Rsine of that multiply the greatest latitude (of the planet) and divide (the product) always by the (corresponding) “divisor” (defined in stanza 48): thus is obtained the latitudes, north or south, of the remaining planets (Mercury and Venus), subtraction (of the degrees of the longitude of the ascending node) should be made from the longitude of the planet’s sighrocca.

The longitude of the planet to be used in the above rule is really the heliocentric longitude and not the geocentric longitude. Brahmagupta (628 A.D.) has therefore prescribed the use of the true-mean longitude of the planet in the case of Mars, Jupiter and Saturn, and that of the longitude of the planet’s *sighrocca* and corrected for the planet *mandaphala* in the case of Mercury and Venus (628 A.D) has therefore prescribed the use of the true-mean longitude of the planet in the case of Mars, Jupiter and Saturn, and that of the longitude of the planet’ *sighrocca* as corrected for the planet’s *mandaphala* in the case of Mercury and Venus.

A rule relating to the distance between two planets which are in conjunction in longitude:

54-55. When the latitudes of the two planets (in conjuction) are of unlike directions, their sum is the (angular) distance between them. When their latitude are of like directions, the minutes of the distance between them are obtained by taking their difference.

The (linear) distance between the two planets (in conjuction) should be announced by those proficient in the processes of planetary conjuction by taking a minute as equivalent to one-fourth or one-half of an *angula*, whichever agrees with the phenomenon observed in the sky.

According to the commentator Paramesvara, one minute of the distance between the two planets is equal to one-half or one-fourth of an *angula,* according as the two planets are or are not near the horizon.

Brahmagupta has critised the longitudinal conjuction of the planets. He favours horizonal conjuction which occurs when the two planets are on the same secondary to the prime vertical, because it can be easily observed.

Diameters of the planets in minutes of arc :

56. Having (first) divided 32 by 5, divide the same number (i.e., 32) again and again by the same (5) as increased by itself in succession (i.e. by 10, 15, 20, and 25): the result thus obtained are known as the minutes of the diameters of Venus, Jupiter, Mercury, Saturn, and Mars respectively.

Definition of the "dividing numbers" for the planets:

57. (Severally) multiply the *yojanas* of the Moon's (mean) distance by the same numbers (i.e. by 5, 10, 15, 20 and 25): the result, in each case, is the "dividing number", in terms of *yojanas,* used in the determination of the *lambana* and *nati* (for the respective planets).

A rule for finding the true distance of a planet, assuming 315 *yojanas* for its diameter, in terms of *yojanas*:

58. (i) These (above-mentioned) "dividing numbers" become accurate when multplied by the "divisor" and divide by the radius.

A rule relating to the determination of the true values of the diameters of the planets in minutes:

58 (ii). So also become the minutes of the diameters when divided by the "divisor" and multiplied by the radius.

The remaining processes concerning the occulttion of one planet by another:

59-60. The determination of the ten Rsines (viz. *madhyajya, drkksepajya, drggatijya, drgya* and *udayajya* - five for each of the two planets concerned) and other remaining determinations should be made as in the case of the Moon. The Rsine of the altitude (for each planet) is to be calculated from the (planet's) own ascensional difference, etc., as taught in connection with the Moon's rising.

In the case of conjuction of the planets (i.e., occulation of one planet by another), the *lambana* and *nati* are prescribed to be found out (by proportion) from the (planets') own "dividing number". The remaining processes such as

the calculation of the sthityardha (i.e. the semi-duration of occultation) are the same as in the case of a (solar)eclipse.

61-62. The predictions of those (astronomers) whose minds are purified by day to day pratice and who have acquired by the grace of the teacher the eye of true conception of the astronomical science, (always) agree with the planetary phenomena and do not go astray as the pure thoughts (desires) of a lovely and devoted wife (do not go astray).

**Chapter VII**

**ASTRONOMICAL CONSTANTS**

Revolutions performed by the planets around the Earth in a period of 43,20,000 solar years (called a *yuga) :*

1-5. The revolution-number (*bhagana)* of the Sun is 43,20,000; of the Moon, 5, 77,53,336; of Saturn, 1,46,564; of Jupiter, 3, 64,224; of Mars, 22,96,824; of Mercury and Venus and of the sighroccas of the other planets, the same as that of the Sun; of the Moon's apogee, 4,88, 219; of (the *sighrocca* of) Mercury, 1,79,37,020; of (the *sighrocca* of) Venus, 70,22,388; and of the Moon's ascending node, 2,32,226.

Intercalary months, omitted lunar days, and civil days in a *yuga*:

6-8. The number of intercalary months (in a *yuga* ) is 15,93,336. For the determination of the number of intercalary months elapsed, (this is the multiplier): the diviser is twelve times the number of solar years in a *yuga* (i.e., 5,18,40,000). The number of omitted lunar days (in a *yuga)* is 2,50,82,580. (For finding the number of omitted lunar days elapsed, this is the multiplier): the divisor is 1,60,30,00,080 (which is the number of lunar days in a *yuga*). The number of civil days in a *yuga* is stated to be 1,57,79,17,500. Inclinations of the orbits of the planets to the ecliptic:

9. The degress of the greatest celestial latitudes of Mercury, Venus, and Saturn are each 2; of Jupiter, 1; and of Mars, 1½.

Longitudes of the ascending nodes of the planets and a rule for finding the celestial latitude of a planet:

10. The degrees of the longitudes of the ascending nodes (of the same planets) are 20, 60, 100, 80, and 40 respectively. The celestial latitude, north or south, (of a planet) should be given out after calculation from the longitude of the planet minus the longitude of its ascending node.

Longitudes of the apogees of planets and the method for finding the *manda* and *sighra* anomalies :

11-12. The degrees of the longitudes of the apogees (of the same planets) are respecitvely 210, 90, 236, and 118. Of the Sun they are to be known as 78.

(In order to get the *manda* anomaly) subtract the longitude of the apogee (of the planet) from the longitude of the planet; and (in order to obtain the *sighra* anomaly) always subtract the longitude of the planet from the longitude of the *sighrocca* (of the planet)

*Manda* and *sighra* epicycles of the planets, and Rsine-differences corresponding to the twenty-four elements of a quadrant;.

13-16. In (the beginning of) the odd quadrants the *manda* and *sighra* epicycles (of Mercury, Venus, Saturn, Jupiter, and Mars) are 7,4,9,7,14 and 31, 59, 9, 16, 53 (respectively); and in (the beginning of) the even quadrants they are stated to be 5, 2, 13, 8,18 and 29, 57, 8, 15, 51 (respectively). Of the Sun and the Moon, the epicycles are 3 and 7 respectively).

The Rsine-differences (corresponding to the twenty-four elements of a quadrant) are 225 (*makhi)*, etc. (as stated by Aryabhata I)

A rule for finding the *bahuphala and kotiphala* etc., without the use of the Rsine-difference table:

17-19. (Now) I briefly state the rule (for finding the *bhujaphala* and *kotiphala* etc. ) without making use of the Rsine-differences, 225, etc.

Subtract the degrees of the *bhuja* (or*koti)* from the degrees of half a circle (i.e. 180). Then multiply the remainder by the degrees of the *bhuja (or koti)* and put down the result at two places. At one place subtract the result from 40500. By one-fourth of the remainder (thus obtained) divide the result at the other place as multiplied by the *antyaphala* (i.e. the epicyclic radius). Thus is obtained the entire bahuphala (or *kotiphala)* for the Sun, Moon, or the star-planets., So also are obtained the direct and inverse Rsines.

The length of the so called circle of the sky and the rule for deriving the length of the orbit of a planet:

20. Multiply the revolution-number of the Moon by 21600: then is obtained the length of the circle of the sky (in terms of *yojanas*). When the circle of the sky is divided by the revolution-number of any given planet, quotient denotes the length of the circular orbit of that planet.

Midnight day-reckoning of Aryabhata I

21. The astronomical processes which have been set forth above come under the sunrise day-reckoning. In the midnight day reckoning too, all this is found to occur: the difference that exists is being stated (below).

The next fourteen stanzas relate to the midnight day-reckoning of Aryabhata I.

Civil days and omitted lunar days in a *yuga* and revolution numbers of Mercury and jupiter:

22. (To get the corresponding elements of the midnight day-reckoning) add 300 to the number of civil days (in a *yuga)* and subtract the same (number) from the number os omitted lunar days (in a *yuga);* and from the revolution-numbers of (the *sighrocca* of) Mercury and Jupiter subtract 20 and 4 respectively.

Diameter of the Earth, the Sun, and the Moon:

23. (In the midnight day-reckoning) the diameter of the Earth is (stated to be) 1600 yojanas; of the Sun, 6480 (yojanas); and of the Moon, 480 (yojanas).

Mean distance of the Sun and the Moon

24. The (mean) distance of the Sun is stated to be 689358 (yojanas); and of Moon, 51566 (yojanas)

Longitudes of the apogees of the planets:

25. 160, 80, 240, 110, and 220 are in degrees the longitudes of the apogees of Jupiter, Venus, Saturn, Mars, and Mercury respectively.

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## Chapter VIII

## EXAMPLES

(Solved Examples)

To find the true lunar day *(tithi)* and the ghatis elapsed at sunrise since the beggining of the current lunar day without the knowledge of the true longitudes of the sun and Moon :

1-4 Multiply the *ahargana* by the number of lunar years (in a *yuga )* and divide by the number of civil days (in a *yuga* ) Then are obtained the mean lunar years , etc. (corresponding to the *ahargana)* by the number of intercalary lunar years ( in a *yuga )* and divide by the number of civil days (in a *yuga )* Thus are obtained the mean intercalary years etc. (corresponding to the *ahargana ) .* The difference between the two denotes the (mean ) solar years, etc. (i.e., years, months, days, and *ghatis )* (corresponding to the *ahargana* ).

The solar years are not required (so they are to be omitted ). From the remaining quantity (in months, days, and *ghatis )* subtract two months and eighteen days. Then (treating the months, days, etc., of the remainder thus obtained as the signs, degrees, etc., of the Sun's mean anomaly ) calculate the (Sun's ) equation of the centre.

Divide the (corresponding) solar time by 12 and apply that to the (mean) lunar days (and ghatis) (obtained from the ahargana) contrarily (i.e., add when the sun's equation of the centre is subtractive and subtract when the Sun's equation of the centre is additive). Also apply one-twelfth of the time corresponding to the Moon's equation of the centre to the resulting lunar days (and ghatis) in the same way as it is applied to the Moon's longitude.

(The lunar days thus obtained are the true lunar days which hare elapsed at sunrise since the begining of the current month).The ghatis obtained above denote the elapsed portion of the current lunar day in terms of ghatis. Multiply those ghatis by 60 and divide by one-twelfth of the difference between the true daily motions of the Sun and Moon,in degrees: the quotient denotes the true time in ghatis (which has elapsed at sunrise since the begining of the current lunar day.).

To obtain the Sun's mean longitude from the Sun's true longitude derived from the midday shadow of the gnomon:

5. Subtract the longitude of the Sun's apogee from the Sun's true longitude derived from the midday shadow (of the gnomon) and (then treating the remainder as the Sun's mean anomoly) calculate the Sun's equation of the centre. Apply that (equation of the centre) to the Sun's true longitude contrarily to the usual law for its substraction and addition.(Treating this result as the mean longitude of the Sun,calculate the Sun's true longitude as before) Repeat the same process again and again (until two successive result agree to minutes). Thus is obtained the mean longitude of the Sun.

The method used here is evidently the method of successive approximations.

To find the arc corresponding to a given Rsine:

6. From the Rsine substract in serial order(as many tabulated Rsine-differences as possible): multiply the number of the Rsine-differences subtracted by 225 and divide by the current Rsine -differentce. Add this result to the previous one. Thus is obtained the arc (corresponding to the given Rsine in terms of minutes).

**EXAMPLES**

Six examples on the shadow of the gnomon:

7. The latitude (of a place) is one and a half degrees minus eight minutes (i.e., 1 22'): and the midday shadow of the gnomon of 12 angulas on level ground is 5 angulas. Give out the Sun's longitude at noon o that day.

8. Quickly say the longitude of the meridian Sun for the place where the latitude is stated to be 8 degrees minus 16 minutes (i.e.,7 44') and the midday shadow of the gnomon, 3 and a half (angulas)

9. Quickly say the true longitudes of the Sun for the places where the latitudes are stated to be 25 and 30 degrees respectively and the lengths of the midday shadows(of the gnomon)are equal to the gnomon (itself).

10. Say what is the longitude of the Sun at the place where the latitude is 15 degree and the prime vertical shadow of (the gnomon due to) the Sun, one and a half angulas together with one-fifth of an angula (i.e., 17/10 angulas).

11. The prime vertical shadow (of the gnomon) is 37 angulas and the equinoctial midday shadow is 30 angulas. Say the longitude of the universal lamp,the sun,find its position on the prime vertical

12. The east-west shadow (of the gnomon) is seen on level ground to be 16 (angulas). The latitude of the place is seven and a half degrees. Say what is the sun's longitude there.

Eleven examples on the pulveriser (kuttakara)

13. The signs, etc., up to the third of the Sun's (mean) longitude have all been carried away by the strong wind; the residue of thirds is known to me to be 101. Tell (me) the Sun's (mean) longitude and also the ahargana.

14. The minutes together with the signs and degrees of the Moon's (mean) longitude have been destroyed being rubbed out by the hands of a child; twenty-five seconds are seen to remain (undestroyed). Calculate from them, o you of noble descent, the ahargthana and the (mean) longitude of the Moon.

15. The (mean) longitude of mercury is 3 signs, 15 degrees, and 5 minutes. Considering this give out the days elapsed (i.e.,the ahargana) and also the revolutions perfomed by him.

By the usual method, we get x=74351419 and y=845180

16. The signs, degrees and minutes of the (mean) longitude of Jupiter have been destroyed by a mischievous child; nine seconds are seen to remain (undisturbed). Say therefrom the ahargana and the mean longitude of Jupiter.

17. The revelutions,etc., up to the minutes of the (mean)longitude fo Venus are destroyed; 10 seconds are found to remain intact. Quickly say (the mean longitudes of) them and also the ahargana (in the two cases)

18. The sum of the (mean) longitudes of Mars and the Moon is calculated to be 5 signs, 7 degrees, and 9 minutes. o you,well versed in the (Arya)bhata-tantra, quickly say the ahargana and also the (mean) longitudes of the Moon and Mars.

19. The difference between the mean longitudes of Mars and Jupiter is exactly 5 signs. Say what is the number of days elapsed since the beginning of Kaliyuga and what are the (mean) longitudes of Jupiter and Mars.

20-21. The sun and Moon on a Sunday at sunrise are carefully seen by me in (the sign) Libra. The degrees of their (mean) longitudes are 12 and 2 respectievely ; the minutes are 1 and 40 respectievely. After how many days will they assume the same longitudes again (at sunrise)on a Thursday,Friday, and saturday respectively? (It is also given that) the (mean) longitude of the Sun is in excess by 17 seconds (over that given above); whereas from the (mean) longitude of the Moon (given above 18 seconds have to be substracted.

22. The revolutions,etc., of the Sun's (mean) longitude, calculated from an ahargana plus a few nadis elapsed, have now been destroyed by the wind; 71 minutes are seen by me to remain intact. Say the ahargana, the Sun's (mean) longitude, and the correct value of the nadis (used in the calculation).

23-24 Some number of days is (severally) divided by the (abraded) civil days for the Sun and for Mars. The (resulting) quotients are unknown to me; the residues, to, arc not seen by me, The quotient obtained by multiplying those residues by the respective (abraded) revolution-numbers and then dividing (the products) by the wind. The remainders of the two (divisions) now exist. The remainder for the Sun is 38472; that for Mars, 77180625. From these remainders severally calculate, o mathematician, the ahargana for the Sun and Mars and also the aharghana conforming to the two residues and state them in proper order.

One example on the determination of the latitude:

24. The Sun being at the end of (the sign)Gemini the length of the night is 21 ghatis. calculate and give out the latitude and also the colatitude of the place.

Authorship and appreciation of the work:

25. This *Aryabhata-karma-nibandha* ('a compendium of astronomical process based on the teaching of AryabhatI') which has clear expressions and simple methods (of calculation) and which can be comprehended even by those with lesser intellect, is written by Bhaskara after full deliberation.

26. Whatever occures in this work regarding the projection and calculation of solar eclipses (etc), which are dealt with by giving numerous rules with clear meaning also finds place elsewhere; and what does not find place here does not occur anywhere else.

**QUOTATIONS**

From the *Maha-Bhaskariya* in Later Work

Passages from the *Maha-Bhaskariya* occur as quotations in the following commentaries:

(1) *Sankaranarayanan's* commentary (869 A.D.) on the *Laghu-bhaskariya.*

(2) *Udayadivakara's* commentary (1073A.D)on the *Leghu-Bhaskariya.*

(3) *Suryadeva's* commentary on the Aryabhatiya and the *Leghu- Manasa.*

(4) *Makkibhatta's* commentary (1377A.D.)on the *Siddhantasekhara.*

(5) *Parameswara's* commentary (1408 A.D.) in the *Laghu-bhaskariya.*

(6) Nilakantha's commantary (c. 1500 A.D.) on the *Aryabhatiya.*

(7) *Govinda Somayaji's* commentary, entitled *Dasadhyayi*, on the Brhajataka of Varahamihira.

(8) *Visnu Sarma's* commentary (c.1363)on the *Vidya-madhaviya.*

## GLOSSARY

### of Terms used in the Maha-Bhaskariya

*Amsa* : (1) Part, fraction
(2) Degree (□)

*Amsaka* : Degree (□)

*Amsumat* : Sun

*Aksa* : (1) Latitude, (2) Five

*Aksakarna* : The hypotenuse of the equinoctial midday shadow (of the gnomon)

*Aksakoli* : Colatitude. Also, sometimes, the Rsine of colatitude.

*Aksayuna* : The Rsine of latitude

*Aksacapa* : The arc of latitude, or simply latitude.

*Aksacapayuna*: The Rsine of latitude

*Aksacapa* : The arc of latitude, or simply latitude.

*Aksacapayuna*: The Rsine of latitude

*Aksajiva* : The Rsine of latitude

*Aksajya* : The Rsine of latitude

*Aksabhaga* : The degrees of latitude

*Aksavalana* : See Valana

*Aksasya valanam*

*Aksavalana* : See Valana

*Aksamsa* : The latitude of a place, terrestrial latitude, or simply latitude.

*Aksamsaka* : Same as Aksamsa

*Aksonnati* : Inclination of the (Earth's) axis, i.e.,the latitude of the place.

*Agata* : Untraversed portion; portion to be traversed.

*Agra* (1) : End. (2) Residue Remainder (3)Agra

*Agraguna* : The Rsine of Agra

*Agra* : The arc of the celestial horizon lying between the east point and the point where a heavenly body rises,or between the west point and the point where a heavenly body sets.

*Angaraka* : Mars

*Angula* : Finger-breadth.

A unit if linear measurement defined by the breadth of eight barely corns.

*Acala* : (1) Seven. (2) Fixed. To make acala in astronomy means to apply the method of successive approximations.

*Aja* : The Sign Aries.

*Ativakra* : A planet is said to be ativakra when it is in the middle of its retrograde motion.

*Adhika-masa* : Intercalary month. The Intercalary months denote the excess of the lunar (synodic) months over the solar months in a certain period. Thus interacalary months in a yuga = lunar months in a yuga-solar months in a yuga.

A true intercalary month is one in which the Sun does not pass from one sign into the next.

*Adhikabda* : Intercalary year, i.e., a collection of twelve intercalary months. See Adhikamsa.

*Adhikaha* : Intercalary day, i.e. intercalary tithi.

*Adhimasa* : Intercalary month. See Adhikamasa

*Adhimasaka* : Same as Adhimasa.

*Adhimasasesa*: The residue of the intercalary months.

*Adhva* : The distance of a place from the prime meridian.

*Adhvana* : Same as Adhva.

*Anudis* : Parallel

*Anupata* : Proportion

*Anuloma* : Direct, A planet is said to be anuloma when its motion is direct, i.e., from west to east.

*Antyaguna* : See Antyajiva

*Antyajiva* : The current Rsine-difference, i.e. the Rsine-difference corresponding to the elementary arc occupied by a planet. In Hindu trigonometry a quadrant of circle is divided into 24 equal parts, called elementary areas.

*Antyajya* : Same as Antyajiva.

*Antyaphala* : Maximum correction due to mandocca or maximum correction due to sighrocca. The former is equal to the radius of the manda epicycle and the latter is equal to the radius of the sighra epicycle.

*Apakrama* : Declination.

*Apakramaguna* : The Rsine of declination

*Apakramajya* : The Rsine of declination.

*Apakramadhanu* : The arc of declination, or simply declination.

*Apagama* : Declination.

*Apacaya* : Decrease.

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*Apama* : Declination.

Apamadhanu : The arc of declination, i.e., declination.

*Apamo gunah* : The Rsine of declination

*Apavarta* : The greatest common divisor; abrader.

*Adbapa* : The lord of the year, i.e., the planet which is the regent of the first day of the year.

*Abhyasa* : Multiplication

*Abhra* : Zero

*Amrtatejas* : Moon

*Amrdadidhiti* : Moon

*Ambara* : Zero

*Ambaroruparidhi* : The work ambara means, according to Hindu astronomers, "that part of the sky which is illuminated by the rays of the Sun". The word admaroruparidhi likewise means "the periphery of the illuminated sphere of the sky".

*Ayana* : The northward or southward course of a planet, particularly the Sun. The ayana of a planet is north or south according as the planet lies in the half-orbit beginning with the sayana sign Capricorn or in that beginning with the sayana sign Cancer.

*Ayuta* : Ten thousand

*Arka* : (1) Sun. (2) Twelve.

*Arkaputra* : Saturn.

*Arkavarsa* : Solar year

*Arkasambhava* : Solar month

(masa)

*Ardhacaturtha* : Three and a half (3½). Literally, four minus half.

*Ardhapancaka* or

*Ardjapanacama* : Four and a half (4½). Literally, five minus half.

*Ardhavistara* : Semidiameter, radius, or 3438’.

*Ardhastamila* : Half set

*Avanati* : (1) Meridian zenith distance. (2) Celestial latitude. (3) Parallax in celestial latitude.

*Avanatilava* : The degree of meridian zenith distance.

*Avanatilavajiva* : The Rsine of avanatilava.

*Avanatiliptika* : Avanti in minutes of arc.

*Avanama* : Zenith distance.

*Avama* : Omitted lunar days or omitted tithis.

*Avamaratrasesa*: The residue of the omitted lunar days.

*Avamasesa* : The residue of the omitted lunar days.

*Avalambaka* : (1) Plumb (2) The Rsine of colatitude.

*Avalambakayuna* : The Rsine of colatitude.

*Avasessa* : Remainder.

*Avisista* : Obtained by applying the method of successive approximations.

*Avisesakarna* : The method of successive approximations.

*Avisesana* : To perform Avisesakarma.

*Avisesatithi* : The tithi (i.e. the time of apparent conjuction of the sun and Moon) obtained by the method of successive approximations.

*Avisesanadi* : The nadis obtained by the method of successive approximation.

*Avisesavidhi* : See Avise sakarma.

*Avislista* : Same as Avisista

*Avisama* : Even

*Asvi* : Two

*Asvin* : Two

*Asti* : Sixteen

*Asakrt* : Repeatedly, or by using the method of successive approximations.

*Asita* : (1) Dark. (2) The unilluminated part of the Moon's disc. (3) Saturn.

*Asita-paksa* : The dark half of a lunar month.

*Asu* : A unit of time equivalent to a lunar month.

*Asrktanu* : Mars. Mars is called asrktanu (asrk = blood, tanu = body) because it is red in coclour.

*Asta* : Setting.

*Astakala* : Time of setting

*Astalagna* : The setting point of the ecliptic, i.e. that point of the ecliptic which lies on the western horizon.

*Astasutra* : The rising setting line (udayastasutra)

*Astodayagrarekha*: The rising-setting line.

*Astodayagrarekha*: The rising-setting line.

*Ahargana* : The number of days elapsed since the beginning of Kaliyuga (or any other epoch)

*Aharmana* : The length of day.

*Ahoratra* : A day and night

*Ahoratra-viskambha* : Day-radius

*Asita* : (1) Dark. (2) The unilluminated part of the Moon's disc. (3) Saturn

*Asita-paksa* : The dark half of a lunar month.

*Asu* : A unit of time equivalent to 4 seconds.

*Asrktanu* : Mars. Mars is called asrktanu (asrk = blood, tanu = body) because it is red in colour.

*Asta* : Setting

*Astakala* : Time of setting

*Astalagna* : The setting point of the ecliptic, i.e. that point of the ecliptic which lies on the western horizon.

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*Ahoratra* : A day and night

*Ahoratra-viskambha* : Day-radius.

*Ahnam ganah* : Same as Ahargana

*Ahnam nicayah* : Same as Ahargana

*Akasa* : Zero

*Apya* : Purvasadha, the twentieth naksatra

*Ayama* : Length

*Ara* : Mars.

*Arki* : Saturn

*Asa* : (1) Direction (2) Ten.

*Asana* : Approximate

*Astambika* : Pertaining to sunset

*Asphujit* : Venus

*Ahnika* : (1)Pertaining to day.

(2) A special astronomical term used by Bhaskara I. See MBh, i. 16-18

*Ina* : (1) Sun (2) Twelve

*Indu* : (1) Moon (2) One.

*Inducca* : Moon's apogee, i.e, the remotest point of the Moon's orbit.

*Indriya* : Five

*Indvahah* : Lunar day or tithi

*Isu* : Five

*Ista* : Given, or desired, or chosen at pleasure.

*Ucca* : The ucca is the apex of a planet's orbit. It is of two kinds: (1) mandocca, i.e. the apex of slow motion, and (2) sighrocca, i.e., the apex of fast motion. In Hindu astronomy, the mandocca is defined to be the remotest point of planets' orbit where the planet' appears smallest. It is therefore the same as the "apogee" of modern astronomy. The sighrocca of the superior planets is an imaginary body which remains in the same direction as the mean Sun; that of an inferior planet lies approximately in the same direction from the Earth as the actual planet is from the Sun.

*Uccabhukti* : (Daily) motion of the ucca; apsidal motion.

*Utkrama* : Reverse order

*Utkramayuna* : Same as Utkramajya

*Utkramajiva* : Same as Utkramajya

*Utkramajya* : Rversed sine (=Radois x versed sine)

*Uttara* : North

*Uttargola* : Northern hemisphere, i.e. the hemisphere lying to the north of the equator.

*Udak* : North

*Udayajya* : The agra of the rising point of a plancet's orbit

*Udayaprana* : Times of rising of the signs measured in asus.

*Udayarasipranapinda* : The time in asus of rising of the rising sign.

*Udayalagna* : The rising point of the ecliptic, i.e., the horizon-ecliptic point in the east.

*Udayasu* : Time of rising (of the signs) on asus.

*Udyastamaya* : Rising and setting.

*Unnati* : Elevation.

*Uparaga* : Eclipse

*Usnatejas* : Sun

*Usnadidhiti* : Sun

*Rtu* : Six

*Aindragna* : The name of the sixteenth nakstra Visakha

*Aindri* : East

*Oja* : Odd

*Kakubh* : Ten

*Kaksya* : Orbit of a planet.

*Kanyaka* : The sign Virgo

*Kapala* : Hemisphere.

*Karana* : (1) Process; working (2) The name of one of the principal elements of Hindu Calendar.

*Karkata* : (1) A pair of compasses. (2)The sign Cancer

*Karna* : (1)The hypotenuse of a right-angled triangle.

(2) The distance of a planet.

*Karnasutra* : Hypotenuse line.

*Kala* : Minute of arc.

*Kalakarna* : The true distance of a planet in minutes of arc.

*Kalanam sesah* : The residue of the minutes (kalasesa)

*Kaliyuga* : According to Bhaskara I, Kaliyuga is a period of 1080000 solar years. The current Kaliyuga began on Friday, February 18, B.C. 3102, at sunrise at Lanka.

*Karmuka* : Arc.

*Kalabhaya* : Degrees of time. A degree of time is equivalent to 60 asus or 10 vinadis.

*Kastha* : (1) Arc. (2) Direction

*Kastha* : Direction.

*Kilaka* : Gnomon

*Kilakagraguna* : Same as Sankvagra

*Kuja* : Mars.

*Kujasa* : South

Kutila : Retrograde

*Kutta* : Pulveriser. See Kuttakara.

*Kuttana* : The process of solving a pulverriser (Kuttakara)

*Kuttakara* : Pulveriser. Equations of the type.

$N = ax + r = by+s$ (1)

or $ax - c = by$ (2) : arc called in Hindu mathematics by the name kuttakara. A kuttukara (pulveriser) is called sagra (residual) or niragra (non-residual) according as it is of the type (1) or (2).

*Kumbha* : The sign Aquarius

| | |
|---|---|
| *Kulira* | : The sign Cancer |
| *Kria* | : Four |
| *Krti* | : Square |
| *Krttika* | : The name of the third naksatra |
| *Kendra* | : (1) Anomaly. The kendra is of two kinds : manda-kendra and sighrakendra. The manda-kendra of a planet is equal to " the longitude of a planet minus the longitude of the planet's mandocca (apogee)," and the sighra - kendra of a planet is equal to the "longitude of the planet;s sighrocca minus the longitude of the planet." (2) Centre. |
| *Kendrajya* | : The Rsine of kendra |
| *Koti* | : See bahu |
| *Kotika* | : Same as koti |
| *Kotiphala* | : The result obtained by multiplying the Rsine of koti due to a planet's kendra by the epicycle and divinding the resulting product by 350. |
| *Kotisadhana* | : Same as kotiphala |
| *Karma* | : (1) Serial order (2) odd quadrant |
| *Kramaguna* | : Same as kramajya |
| *Kramajya* | : Rsine (= Radius x sine) |
| *Kranti* | : Declination |
| *Kriya* | : The sign Aries |
| *Ksamadina* | : Civil day |
| *Ksitiguna* | : Same as ksitijya |
| *Ksitijaguna* | : Same as ksitiguna |
| *Ksitija* | : A corrupt from of kritijya |
| *Ksitijiva* | : Same as ksitijya |

*Ksitijya* : Earthshine. The distance between the rising-setting line and the line joining the points of intersection of the diurnal circle and the six o' clock circle.

*Ksitidhara* : Seven

*Ksitiputra* : Mars

*Kritimaurvi* : Same as Ksitijya

*Ksipti* : Celestial latitude

*Ksetranirmana*: Celestial longitude

*Ksepa* : Quantity to be added

*Ksonidhara* : Seven

*Kha* : Zero

*Khamadhya* : Meridian

*Khecara* : Planet

*Gagana* : (1)Meridian (2) Zero

*Gaganasya urttain* : The circumference of the sky. See Ambaroruparidhi

*Gana* : Used in the sense of Bhagana

*Gata* : Traversed, elapsed

*Gali* : Motion. Generally used in the sense of "daily motion".

*Gantavya* : To be traversed.

*Guna* : (1) Multiple or multiplication. (2) Rsine. (3) Three

*Gunakara* : Multiplier, coefficient

*Gunapratana* : Rsine

*Gunaphala* : Bahuphala and kotiphala

*Guru* : Jupiter.

*Graha* : Sign

*Go* : The sign Taurus.

*Gola* : Hemisphere.

*Golakhanda* : The semidiameter of the (celestial) sphere.

*Golabheda* : Same as Golakhanda

*Graha* : (1) Planet (2) Eclipse

*Grahaganita* : Astronomy

*Grahacara* : Motion of a planet

*Grahana* : Eclipse

*Grahatanu* : A special term used by Bhaskara I.

*Grahadeha* : Same as Grahatanu

*Grahayoga* : Conjunction of planets.

*Grahanam tanuh* : Grahatanu

*Grahoparaya* : (1) Eclipse. (2) Measure of an eclipse. (3) Beggining of an eclipse.

*Grasamadhya* : The middle of an eclipse

*Grasasalaka* : A needle (or line) of length equal to the portion of the diameter eclipsed.

*Grasadi* : The beginning of an eclipse.

*Grahaka* : The eclipsing body, the eclipser

*Grahya* : The eclipsed body.

*Ghatika* : Same as Ghati.

*Ghati* : A unit of time equivalent to 24 minutes.

*Ghana* : Cube

*Ghata* : Product, multiplication

*Cakra* : Circle, twelve signs, or 360.

*Caturasra* : Quadrilateral

*Candra* : (1) Moon (2) One

*Candrika* : Same as Candra

*Cara* : Ascensional difference. It is defined by the arc of the celestial equator lying between the six O'clock circle and the hour circle of a heavenly body at rising.

*Caradala* : Ascensional difference. See Cara.

*Cala* : Sighrocca

*Caliccoa* : Sighrocca.

*Capa* : (1) The sign Sagittarius (2) Arc.

*Cara* : Motion or daily motion

*Citra* : The name of the fourteenth naksatra.

*Caitra* : The name of the first month of the year.

*Chaya* : Shadow. (2) The Rsine of the zenith distance.

*Chayadairaghya* : Same as Bhucchayadairaghya.

*Chayabhramana* : The path of the end of the shadow (of the gnomon)

*Chidra* : Nine.

*Cheda* : Divisor or denominator

*Chedyaka* : Projection, or graphical representation.

*Jaladhara* : Four

*Jaladhi* : Four

*Jalapadik* : West

*Jalesadik* : West

*Jina* : Twenty four

*Jiva* : Jupiter

*Jivadina* : Thursday

*Jiva* : (1) Rsine (=Radius x sine). (2) The Rsine differences corresponding to the twenty-four divisions of the quadrant.

*Jivabhukli* : True daily motion derived with the help of the table of Rsine differences.

*Juka* : The sign Libra

*Jna* : The planet Mercury

*Jya* : Same as Jiva.

*Jyasankalita* : Used in the sense of "the given Jya"

*Jyau* : Jupiter.

*Tatpara* : Third of arc, i.e. one-sixtieth of a second of arc.

*Tattva* : Twentyfive

*Tantra* : Principle, doctrine, theory, rule, method. Also a class of astronomical works.

*Tama* : (1) The shadow of the Earth, particularly, the section of the shadow cone where the Moon crosses it, by a plane perpendicular to the axis of the shadow cone. (2) The Moon's ascending node.

*Tamomaya* : The Moon's ascending node.

*Taraka* : Star

*Tara* : Star

*Taragraha* : The star planets. The planets Mars, Mercury, Jupiter, Venus, and Saturn are called star planets (targraha) in Hindu astronomy.

*Tigmamsu* : (1) The Sun. (2) Twelve.

*Tithi* : (1) Lunar day (called tithi). (2) Time of conjunction or opposition of the Sun and Moon. (3) Time of beginning, middle, or end of eclipse. (4) Fifteen. (5) Thirty.

*Tithipranasa* : Omitted tithis

| | |
|---|---|
| *Tithganta* | : Time of conjunction or opposition of the Sun and Moon. |
| *Tiryak* | : (1) Oblique. (2) Transverse. |
| *Tunga* | : Same as Ucca |
| *Turya* | : One-fourth |
| *Tula* | : The sign Libra |
| *Tuladhara* | : The sign Libra. |
| Trigrahaguna | : The Rsine of three signs i.e. the radius or 3438'. |
| *Trijya* | : Radius or 3438' |
| *Tribhavana* | : Three signs. |
| *Trimaurvi* | : Radius |
| *Trairasika* | : Rule of Three. |
| *Dala* | : Half |
| *Dasaguna* | : The ten Rsines, viz. Sun's udayajya, Sun's madhyajya, Sun's drkksepajya, Sun's *drugjya*, Sun's drggatijya, Moon's udayajya, Moon's udayajya, Moon's madhyjya, Moon's mandhyajya, Moon's drkksepajya, Moon's *drgjya*, and Moon's drggatijya. |
| *Dasajiva* | : Same as Dasaguna |
| *Dasara* | : Two |
| *Dahana* | : Three |
| *Dik* | : (1)Direction(2) Ten |
| *Dikka* | : Direction |
| *Ditisunupujita* | : Venus. |
| *Dina* | : (1) Day. (2) Fifteen |
| *Diragana* | : Same as Ahargana |

*Dinamana* : Measure (or length) of the day

*Dinarosi* : Ahargana

*Dinanam ganah* : Same as Ahargana

*Divasa* : (1) Day (2) Aharyana

*Divasagynardha* : The day redius

*Divasajiva* : The day radius

*Divasayojana* : The number of yojanas that a planet traverses in a day

*Divasavistarabheda* : The day radius.

*Divaguna* : The day radius.

*Divicara* : (1) Seven (2) Planet

*Dis,* : (1) Director. (2) Ten.

*Drkksepa* : The drkksepa is the shortest arcual distance of the planet's orbit from the zenith. It is also used for the Rsine of that distance.

*Drggati* : Arc corresponding to the Drggatijya.

*Drggatijya* : The drggatijya is the distance from the zenith of the plane of a planet's circle of celestial longitude, or the Rsine of the shortest distance the zenith of a planet's circle of celestial longitude.

*Drgguna* : The R sine of zenith distance.

*Drgjiva* : The Rsine of zenith distance.

*Drgjya* : The Rsine of zenith distance.

Drdha : Prime

*Drsya-candra* : The longitude of the Moon corrected for the visibility corrections.

*Devapujya* : Jupiter

*Devamantri* : Jupiter

*Desakala* : Used in the sense of desantara-kala, i.e. the longitude-correction in terms of time.

*Desajata* : The longitude of the place. That is, either the distance of the local place from the prime meridian, or the difference between the local and standard times.

*Desantara-karma* : Correction for the longitude of the place, the longitude correction.

*Desantara-ghati* : Desantra in ghatis.

*Deha* : Used in the sense of grahadeha. See Grahadeha

*Dyugana* : Ahargana

*Dyujya* : The day radius.

*Dyuti* : Shadow (meaning) " the shadow of the gnomon")

*Dyuti-karna* : The hyotenuse of the shadow (of the gnomon)

*Dhudala* : The day radius

*Dyurasi* : Ahargana

*Dyuvyasa* : The day radius

*Dyuvyasa-bheda* : The day radius.

*Dyuvaysadha* : The day radius.

*Dvyagra* : Residual pulverser with two residues.

*Dhana* : Addition

*Dhanistha* : The name of the twenty-third naksatra.

*Dhanuh* : (1) Arc. (2) The sign sagittarius.

*Dhanuh-khanda* : In Hindu astronomy, the quadrant of a circle is divided into twenty-four equal parts and these

parts are known as kasiha, dhanu, dhanuhkhanda, dhanurbhaga, etc.

*Dhanubhaga* 225’

*Dhanus* : (1) Arc (2) 225’

*Dhanvin* : The sign sagittarius

*Dharanidina* : Civil day.

*Dharasuta* : Mars

*Dhatridhara* : Seven

*Dhrti* : Eighteen

*Dhruvaka* : A technical term.

*Naksatra* : (1) Star. (2) Asterism. (3) Twenty-seven

*Naksatragana* : Same as Bhagana

*Naksatra-bheda* : Occultation of stars.

*Nakha* : Twenty

*Naga* : Seven

*Natabhaaga* : The degrees (bhaga) of zenith distance (nata)

*Natamsa* : Zenith distance.

*Nati* : (1) The meridian zenith distance. (2) Celestial latitude as corrected for parallax in latitude.

(3) Parallax in latitude

*Natijya* : The Rsine of the meridian zenith distance.

*Nanda* : Nine

*Nabha* : Zero

*Nara* : (1) The sign Gemini. (2) Gnomon. (3) The Rsine of altitude.

*Na* : The Rsine of altitude

*Nadika* : A unit of time equivalent to 24 minutes.

*Nadi* : See Nadika.

*Niraksa* : Equator.

*Niraksasu* : Asus of the right ascension, i.e., the time in asus of rising at the the equator.

*Nirapavartita* : Unabraded, unabridged.

*Nisakara* : (1) Moon (2) One

*Niscalakriya* : Methos of successive approximations.

*Nihsvasalava* : Asus

*Nr.* : Gnomon

*Netra* : Two

*Nemi* : Circumference, periphery

*Paksa* : (1) Lunar fortnight, period from new moon to full moon, or from full moon to new moon. (2) Two

*pada* : Quadrant. (2)Square root

*Parakranti* : (Sun's) greatest declination, or obliquity of the ecliptic.

*Parmapama* : Same as parakranti.

*Paridhi* : (1) Circumference, periphery. (2) Epicycle

*Parilekha* : Projection, graphical representation.

*Parvala* : Seven

*Parvamadhya* : The middle of the eclipse.,

*Pala* : Latitude

*Palajiva* : The Rsine of the latitude,

*Palajya* : The degrees of the latitude.

*Palabhaga* : The degrees of the latitude

*Palangula* : Used in the sense of 'palabhangula', i.e. the angulas of the equinoctial midday shadow.

*Palamsa* : The degree of the latitude

*Pascardha* : The western half.,

*Pata* : The ascending node of a planets orbit (on the ecliptic)

*Parabhaga* : The degrees of the longitude of the ascending node.

*Puskara* : Three

*Purvalagna* : The horizon-ecliptic point in the east.

*Pankti* : Ten

*Pratimandala* : Eccentric.

*Pratimandala-karna* : Processes under the eccentric theory.

*Prabha* : (1) The shadow of the gnomon. (2) The Rsine of the zenith distance.

*Pralayastithinam* : Omitted lunar days.

*Prastara* : The statement of possible combinations in a serial order.

*Praggrasa* : The first contact in an eclipse.

*Prana* : Same as Asu

*Praleyarasmi* : One

*Pronnati* : Altitude

*Phala* : (1) Result. (2) Correction

*Bhava* : The first of the seven movable karnas. The karna is one of the five important elements of the Hindu Calendar.

Bahula : The naksatra Krttika.

Bahu : The base (of a right-angled trangle). The upright of a right-angled triangle is called koti. (2) The bahu corresponding to a planets anomaly. This is the arcual distance of the planet from the its apogee or perigee whichever is nearer. Suppose that is the anomaly of a planet (or any arc,

whatever) If is less thanthan /2, ifself is the bahu; If 0 is greater the /2 but less than , (-0) is the bahu; and if 0 is greater thatn 3/2, (2-0) is the bahu. The complement of the bahu is called koti.

*Bahuka* : Same as bahu.

*Bahujya* : The Rsine of the bahu (of a planet's anomaly)

*Bahuphala* : See notes on MBh, iv. 6

*Bahoh phalam* : Same as Bahuphala

*Bimba* : The dise of a planet

*Bimbardhu* : The semi diameter of the disc

*Budhasa* : North

*Bham* : Twenty-seven

*Bhaga* : The naksatra Purva phalguni, the regent of which is Bhaga.

*Bhagana* : (1) The revolution-number of a planet, i.e., the number of revolutions that a planet performs in a certain period. The revolutions given by Bhaskara I correspond to a yuga, i.e., to a period of 43,20,000 years. (2) The naksatras.

(3) Twelve signs (or 360)

*Bhava* : Eleven

*Bhavana* : Sign

*Bhaga* : (1) Part, fraction, (2) Division. (3) Degree

*Bhagaladbha* : Quotient

*Bhagaseas* : The residue of the degrees.

*Bhagahara* : Divisor

*Bhagaharaka* : Same as Bhagahara

*Bhajya* : Dividend

*Bhargava* : Venus

*Bhidah* : Half

*Bhukli* : Motion, or daily motion

*Bhuja* : Same as *Bhja*

*Bhujantara* : Correction for the equation of time due to the eccentricity of the ecliptic.

*Bhujaphala* : The equation of the centre.

*Bhucchaya* : The Earth's shadow

*Bhucchayadairghya* : The length of the Earth's shadow, i.e. the distance of the vertex of the shadow cone from the Earth's centre.

*Bhujya* : See Ksitijya

*Bhuta* : Five

*Bhudina* : Civil day.

*Bhudicasa* : Civil day.

*Bhudhara* : Seven

*Bhubrt* : Seven.

*Bhumidina* : Civil day.

*Bhrgu* : Venus

*Bhumidina* : Civil day.

*Bhrgu* : Venus.

*Bhrguja* : Venus.

*Bheda* : (1) Half, (2) Occulation of the heavenly body.

*Bhoga* : Motion

*Bhauma* : Mars.

*Maghavadgura*: Jupiter

*Magha* : Name of the tenth naksatra

*Mandala* : Circle; a collection of 12 circle.

*Mandalamadhya* : The centre of a circle

*Mati* : An optional number

*Matsya* : Fish-figure

*Madhu* : Caitra, the first month of the year

*Madhyakranti* : The declination of the merdian ecliptic point.

*Madhyacchaya* : The midday shadow (of the gnomon)

Madhyajatah

*Lambakah* : The upright due to the meridian-ecliptic point, i.e. the Rsine of the altitude of the meridian ecliptic point.

Madhyajya : The Rsine of the zenith-distance of the meridian -ecliptic point; the meridian-sine.

*Madhyaparinisthit-*

*alambaka* : Same as Madhyajataj lambakah.

*Madhyalayna* : Meridian ecliptic point.

*Madhyasuryavanama* : The zenith distance of the midday Sun, or the meridian zenith distance of the Sun.

*Madhyavanati* : The zenith distance of the midday Sun.

*Mandakendra* : Manda anomaly (=longitude of the planet minus longitude of the planet's apogee)

*Mandapata* : See MBh, vii

*Mandaphala* : Correction due to the planet's mandocca. In the case of the Sun and Moon, the equation of the centre.

*Mandamanurviphalacapa* : Same as Mandaphala.

*Mandavrita* : Manda epicycle

*Mandasiddha* : Corrent for the mandaphala.

*Mandasiddhi* : Correction (of a plnet) for the mandaphala

*Mandantyajiva*: The present Rsine-difference corresponding to the mandakendra i.e. the Rsine-difference of the clementary arc in which the planet lies.

*Mandocca* : The apogee of a planet.

*Mandoccakarna* : See Mandakarna

*Mandocckendra* : See Mandakendra

*Mandoccavrtta* : Manda epicycle.

*Mithuna* : The sign Gemini

*Mina* : (1) Fish-figure, (2) the sign Pisces

*Muni* : Seven

*Mula* : Square root

*Mrga* : The sign Capricorn

*Mesa* : The sign Aries.

*Maitra* : The naksatra Anuradha

*Moksa* : The separation of the eclipsed body after an eclipse.

*Maurika* : Minute of arc.

*Maurvi* : Rsine

*Yantra* : Instrument

*Yama* : (1) Saturn (2) Name of the second naksatra Bharani, whose divinity is Yama. (3) Two.

*Yamala* : Two

*Yamya* : South

*Yamyagola* : The southern hemisphere, i.e. the hemisphere lying to the south of the equator.

*Yamyottara* : South-north

*Yamyottarayata* : Directed south-to-north

*Yugala* : Two

*Yugma* : Even

*Yoga* : (1) Addition. (2) conjunction of two heavenly bodies.

*Yogatara* : Junction stars. These are those prominent stars of the twenty-seven naksatras which were used by the Hindu astronomers for the study of the conjunction of the planets, especially the moon, with them.

*Yogabhaga* : The degrees of the longitudes of the junction-stars.

*Yojana* : The yojana is a measure of distance. The length of a yojana is different at different places at different places and at edifferent times. The yojana of Aryabhata I and Bhaskara I is roughly equivalent to 7½ miles.

*Randhra* : Nine.

*Ravi* : (1) Sun (2) Twelve.

*Ravija* : (1) Saturn (2) A special term used by Bhaskara I.

*Ravijadivasa* : A special term used by Bhaskara I.

*Rasa* : Six

*Rama* : Three

*Rasi* : (1) Quantity (2) Sign

*Rasijiva* : The Rsine of one sign, i.e. Rsin (30□)

*Rahu* : The Moon's ascending node.

*Rudra* : Eleven

*Rudhira* : Mars.

*Rupa* : One

*Lagna* : The horizon ecliptic point in the east.

Laghutantra : Short or simplified methods.

*Lanka* : A place in 0 latitude and 0 longitude. Also see *supra, p.47*

*Lankarasyudaya* : Times of rising of the signs of Lanka, or right ascensions of the signs.

*Lankodaya* : Times of rising (of the signs) at Lanka, or right ascensions (of the signs).

*Labdha* : Quotient

*Lamba* : The Rsine of the colatitude (of the place)

*Lambaka* : The Rsine of the colatitude

*Lambakaguna* : Same as Lambaka

*Lambana* : Parallax in longitude; or in particular, the difference between the parallaxes in longitude of the Sun and Moon.

*Lambanalipta* : Lambana in longitude in terms of minutes of arc.

*Lambanantara* : The lambana-difference.

*Lambanantaranadika* : The nadis of the lambana-difference, or the lambana-difference in terms of nadis.

*Lava* : (1) Part, portion, fraction. (2) Degree.

*Lipta* : Minute of arc

*Liptika* : Same as Lipta

*Liptika vipurva*: Viliptika; second of arc.

*Vakra* : Retrograde

*Vakragati* : Retrograde motion.

*Vakrayamana* : Retrograde motion.

*Vakrigraha* : A planet in retrograde motion.

*Vacasam patih*: Jupiter.

*Vatsara* : Year

*Vapu* : The body (globe or disc) of a planet

*Varga* : Square

*Vartamana* : Present, current

*Vartamanaguna* : The present (or current) Rsine-difference, i.e., the Rsine difference of the elementary arc occupied by a planet.

Varsapa : The lord of the year i.e., the planet after whose name the first day of the year bears its name.

Valana : Deflection. Valana relates to an eclipsed body. IUt is the angle subtended at the body by the arc joining the north point of the calestial horizon and the north pole of the ecliptic. Valana is generally divided into two components, (i) Aksavalana and (ii) Ayanavalana. The Aksavalana is the angle subtended at the body by the arc joining the north point of the celestial horizon and the north pole of the equator. The Ayanavalana is the angle subtended at the body by the arc joining the north poles of the equator and the ecliptic.

The Valana is also defined as follows: The great circle of which the eclipsed body is the pole is called the horizon of the eclipsed body. Suppose that the prime vertical, equator, and the ecliptic intersect the horizon of the eclipsed body at the points A, B and C towards the east of the eclipsed body. Then are AB is called the Aksavalana, arc BC is called the Ayanavalana and are AC is called Valana.

Valana is also called spastavalana.

*Vasu* : Eight.

*Vahni* : Three

*Varuni* : West

*Vi* : Celestial latitude. Evidently, vi is an abbreviated from the viksepa.

*Vikala* : Second of arc.

*Vikastha* : The arc of celestial latitude.

*Viksipti* : Celestial latitude

| | |
|---|---|
| *Vihsepa* | : Celestial latitude |
| *Viksepajya* | : The Rsine of celestial latitude. |
| *Viksepamsa* | : The degrees of celestial latitude. |
| *Vighatika* | : A unit of time, equivalent to 24 seconds. |
| *Vidis* | : Contrary direction. |
| *Vinadika* | : Same as Vighatika. |
| *Vinadi* | : Same as Vinadika |
| *Vipritaguna* | : Rversed-sine |
| *Vipulacchaya* | : Great shadow, meeting "the Rsine of the zenith *distance".* |
| *Vipulanara* | : Great gnomon, meaning "The Rsine of altitude". |
| *Vinandala* | : The orbit of a planet |
| *Vimardadha* | : Half the duration of totality of an eclipse |
| *Vimaurika* | : Second of arc. |
| *Viyat* | : Zero |
| *Vilagna* | : The horizon-ecliptic point in the east. |
| *Vilipta* | : Second of arc. |
| *Viliptika* | : Same as Vilipta |
| *Vivara* | : Difference, intervening space. |
| *Visakha* | : Name of sixteenth naksatra |
| *Visesa* | : Difference |
| *Vislesa* | : Difference. |
| *Visva* | : Thirteen |
| *Visama* | : Odd. |
| *Visaya* | : Five |
| *Visuvajya* | : The Rsine of the latitude (of a place) |
| *Visuval* | : The equator. |

*Visuvakarna* : The hypotenuse of the equinoctial midday shadow.

*Visuvatprabha* : The equinoctial midday shadow.

*Visuvadudayarasi-*

*pranapinda* : Time in asus of rising of the signs at the equator, i.e., right ascension of the signs in terms of asus.

*Viskambha* : Diameter

*Visnukrama* : Three

*Vistara* : Same as Vistara

*Vistara* : (1) Diameter. "Vyasa, viskambha, and vistara are synonyms", says Bhaskara I. (2) Length, breadth, etc. "Ayama, vistara, and dairghya are synonyms", says Bhaskara I

*Vihangama* : Planet.

*Vihaga* : Planet

*Vihayas* : Zero

*Vrtta* : (1) Circle. (2) Epicycle

*Vrttasankhya* : The length of the circumference of a circle

*Vrnda* : Cube

*Vrsa* : The sign Taurus.

*Veda* : Four

*Velakutta* : Time-pulveriser.

*Vaidhrta* : An astronomical phenomenon.

*Vaisuvati chaya* : The equinoctial midday shadow.

*Vyatipata* : An astronomical phenomenon.

*Vyasa* : Diameter

*Vyasakhanda* : Radius

*Vyasakhandanicaya* : Same as Vyasakhanda.

*Vyasardha* : Radius or 3438′.

*Vyoma* : Zero

*Sakrataraka* : The naksatra Jyestha, whose regent is Indra.

*Sakragura* : Jupiter

*Sanku* : (1) Gnomon. (2) The Rsine of altitude (of a heavely body)

*Sankagra* : The distance of the projection of a heavenly body on the plane of the celestial horizon from the planet's resing-setting line.

*Sankvagrajiva* : Same as Sankvagra.

*Satabhisak* : The naksatra Satabhikha

*Sapharika* : A fish figure.

*Sara* : (1) Rversed-sine. (2) One

*Sasija* : Lunar

*Salin* : One

*Sikhi* : Three

*Silimukha* : Five

*Silocca* : Seven

*Siva* : Eleven

*Sighra* : Same as Sighrocca

*Sighrakarna* : The distance of a planet obtained by the sighrocca process.

*Sighrakendra* : The sighra anomaly.

*Sighrakendraphala* : Sighraphala, i.e, correction due to the sighrocca.

*Sighrajah karnah* : Sighrakarna

*Sighranyayapatacapa* : Sighra epicycle

*Sighrapata* : See MBh

*Sighravrtta* : Sighra epicycle

*Sighrasiddha* : Corrected for the sighraphala.

*Sighrantyajiva* : The present Rsine-difference relating to the *sighra (kendra)*

*Sighroccavrtta* : Sighraepicycle.

*Sitakirana* : (1) Moon (2) One.

*Sitarasmi* : (1) Moon. (2) One

*Sitamsu* : (1) Moon (2) One.

*Sukla* : The illuminated part of the Moon's disc; the *phase of the Moon.*

*Srngonnati* : The elevation of the Moon's horns.

*Saila* : Seven

*Sodhana* : Subtraction.

*Sodhaniya* : A subtractive quantity technically called sodhaniya or sodhya.

*Sodhya* : See Sodhaniya

*Sauklya* : The illuminated part of the Moon's disc.

*Sravana* : (1) Name of the 22nd naksatra. (2) The Hypotenuse (of a right-angled traiangle)

*Samskrta* : Corrected.

*Sankalita* : Meridian zenith distance

*Sama* : Even

*Samamandala* : The prime vertical

*Samamandalaja cjaya* : The prime vertical shadow.

*Samamandalasanku* : The Rsine of the prime vertical altitude.

*Samarekha* : The prime vertical altitude.

*Samarekha* : The prime meridian.

*Samalipta* : Two planets are said to be samalipta When their longitudes are equal up to minutes.

*Samavalambajya* : The Rsine of the colatitude.

*Sarvapama* : The greatest declination (of the Sun), i.e., the obliquity of the ecliptic.

*Sagara* : Four

*Sarpamastaka* : An astronomical phenomenon.

*Simha* : The sign Leo

*Sita* : (1) The illuminated part of the Moon's disc; the phase of the Moon. (2) The light half of the month. (3) Venus

*Sitakhaya* : Venus

*Sitapaksa* : The light half of a lunar month, light fortnight.

*Sitabindu* : The point of the Moon's diameter whcih lies at the end of the illuminated part of the Moon.

*Sitamana* : The measure of the illuminmated part of the Moon's disc.

*Suranathagura*: Jupiter

*Surapadik* : East

*Suredya* : Jupiter

*Suri* : Jupiter

*Surya* : (1) Sun (2) Twelve.

*Suryakaksya* : The orbit of the Sun, the ecliptic.

*Suryaja* : Saturn.

*Saimhikeya* : The ascending node of the Moon's orbit. (Saimhikeya literally means Rahu, son of Simhika)

*Somaja* : Mercury

*Somasunu* : Mercury

*Saumya* : (1) North. (2) The naksatra Mragasira. (3) Mercury

*Sauri* : Saturn

*Sthiti* : Duration (of an eclipse)

*Sthitidala* : Half the duration (of an eclipse)

*Sthityardha* : Half the duration (of an eclipse)

*Sthula* : Gross, approximate

*Sparsa* : Contact

*Sparsakala* : Time of the first contact (in an eclipse)

*Spasta* : True, corrected.

*Sphuta* : True

*Sphuamadhya* : True mean; the tube-mean planet.

*Sphutayojana* : Used in the sense of sphutayojanakarna

*Sphutayojanakarna* : The true distance (of a planet) in terms of yojanas.

*Sphutavritta* : True or corrected epicycle.

*Svara* : Seven

*Harija* : Horizon

*Hara* : Divisor

*Hararasi* : Divisor

*Himamsu* : (1) Moon (2) One

*Hina* : (1) Less (2) Omitted lunar day (hinadivasa)

*Hinadivasa* : Omitted lunar day.

*Hinaratra* : Same as Hinadivasa

*Hutasana* : Three.

(Names which gives numbers are based on Bhoothasankhya system)

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